SCIENTIFIC AGRICULTURE

Volume 25 JANUARY, 1945 No. 5

THE ACID-OXALATE EXTRACTS OF PODZOL AND PODZOLIC SOILS[1]

P. G. LAJOIE[2] AND W. A. DELONG[3]

Macdonald College, Quebec

The acid ammonium oxalate extraction method of Tamm (9) has been applied to the study of the problems of soil genesis and of the differentiation of podzol, brown forest, and ground-water soils. Thus, Lundblad (7) and Hoon (6) have found marked differences in the amounts of silica and of sesquioxides extracted from the various horizons of soils of the classes mentioned. The procedure is considered to give an approximate measure of the quantities of reactive weathering products in the soil.

It was thought possible that the Tamm procedure might have some usefulness in the differentiation of soil types. The objective of the present investigation was to test this possibility in the case of a number of podzolized soils. Duplicate, in one instance triplicate, profiles of 7 soil types were examined with this end in view. These 7 types have been classified (2) as belonging to the following soil groups: podzols, ill-drained podzols and brown podzolics, with one soil described as transitional between the podzols and the brown podzolics. In the present report this transitional soil has been classed as a brown podzolic for purposes of discussion. Some information on these soils is presented in Table 1. They are more fully described elsewhere (2).

[1] Based on a thesis presented by P. G. Lajoie to the Faculty of Graduate Studies of McGill University in partial fulfilment of the requirements for the degree of Master of Science. Contribution from the Faculty of Agriculture, McGill University, Macdonald College, Que., Canada. Macdonald College Journal Series No. 200 Presented before a meeting of the Soils Group of the Canadian Society of Technical Agriculturists of Toronto, Ontario, June 27-29, 1944.
[2] Soil Specialist, Experimental Farm Service, Dominion Department of Agriculture, presently stationed at Macdonald College, Quebec.
[3] Associate Professor of Chemistry.

TABLE 1.—DESCRIPTION OF SOILS STUDIED

Soil group	Soil type	Dominant parent materials
Podzols	Ascot s. loam (2)*	Non-calciferous slates and shales.
	Greensboro loam (2)	Slate; impure limestone.
	Greensboro loam, strongly rolling phase (2)	Slate; impure limestone.
Poorly-drained podzols	Magog stony loam (2)	Non-calciferous slates and shales.
	Brompton stony loam (3)	Slate; sandstone.
Brown Podzolic	Berkshire loam† (2)	Schist.
	Woodbridge loam (2)	Schist.

* Indicates the number of profiles studied.
† Considered as transitional between the podzols and the brown podzolic soils.

EXPERIMENTAL

In the collection of the podzol samples no attempt was made to separate an A_1 horizon, the profiles of this class examined being practically devoid of this horizon. The horizon designated as A_0 therefore includes all the soil between the litter and the A_2 in the case of the podzol profiles studied.

All analytical determinations were made on air-dry soil passing a 1.0 mm. sieve. The following characteristics were determined: loss on ignition, pH, and the amounts of silicon, iron, aluminium, titanium manganese and phosphorus brought into solution by extraction with the Tamm reagent.

The pH values were determined electrometrically using a glass electrode and a Hellige pH meter at a soil: water ratio of 1 : 2.5. The results for loss in ignition and pH are shown in Table 2.

The acid ammonium oxalate reagent was prepared according to the method of Lundblad (7). The extractions with this reagent were made by placing 5-gram samples of soil in 250 ml. Erlenmeyer flasks containing 100 ml. of the solution and shaking continuously for 30 minutes on a horizontal rotating shaking machine. The mixture was then filtered by

TABLE 2.—MEAN PERCENTAGE VALUES FOR LOSS ON IGNITION AND pH RANGES

Horizon	Podzols		Ill-drained podzols		Brown podzolics	
	Loss on ignition	pH range	Loss on ignition	pH range	Loss on ignition	pH range
A_0	33.4	3.7–4.6	22.7	4.1–6.0	16.7*	4.5–4.9*
A_2	2.7	4.0–4.6	3.5	4.0–6.2	6.0†	4.5–4.6†
B_1	11.0	4.1–4.8	2.0	5.5–6.8	6.4	4.7–5.2
B_2	5.7	4.6–5.1	—	—	4.8	5.0–5.3
C	2.0	4.8–5.9	1.3	5.6–6.9	2.2	5.1–5.8

* Average values for the A_0 horizon of the Berkshire soils and the A horizon of the Woodbridge soils.
† Loss on ignition and pH values for the Berkshire soil only.

suction using a No. 5 Whatman paper, the residue returned to the flask and the extraction repeated. Finally, the residual soil was washed with 25 ml. of the extracting solution. The filtrates and washings were taken to dryness on the steam bath and ignited at 550° C. The ignited residues were dissolved in concentrated hydrochloric acid and the solution taken to dryness to dehydrate the silica. After dissolving the sesquioxides in HCl solution the filtrate was again dehydrated to ensure complete recovery of silica. The total silica was determined gravimetrically. The filtrate and washings from the silica separation were made up to a volume of 200 ml. and suitable aliquots taken for the determination of manganese, titanium, iron and phosphorus. The remainder of the solution was used for the determination of total sesquioxides, that is, of the oxides of iron, aluminium, titanium and phosphorus without manganese. The method used was that of Hillebrand and Lundell (5).

Iron, phosphorus, titanium and manganese were determined colorimetrically, iron by the method of Dyer and McFarlane (3), phosphorus by

that of Dyer and Wrenshall (4), titanium by the procedure of Hillebrand and Lundell (5, p. 456), and manganese by that of Richards (8). Alumina was estimated as the difference between the total sesquioxide minus the sum of the oxides of iron, titanium and phosphorus.

RESULTS AND DISCUSSION

The data obtained for the amounts of silica extractable from these soils by the Tamm reagent are given in Table 3. The podzols and the transitional Berkshire soil showed, as expected, very small amounts of oxalate-soluble silica in the A_2 horizons, with some accumulation of this component in the B horizons, especially in the B_2. The amount of this fraction was low and uniform throughout the profiles of the ill-drained podzols and of the brown podzolic Woodbridge soil.

TABLE 3.—MEAN VALUES FOR EXTRACTABLE SILICA AS PERCENTAGE OF DRY SOIL

Horizon	Podzols	Ill-drained podzols	Transitional (Berkshire)	Brown podzolic (Woodbridge)
A_0	.03	.03	.05	.08
A_2	.03	.03	.02	—
B_1	.16	.03	.08	.04
B_2	.25	—	.10	.08
C	.10	.04	.09	.07

The molar silica-sesquioxide ratios shown in Table 4, exhibited the expected zig-zag pattern in the podzol profiles, were relatively uniform throughout the profile in the brown podzolic soils, and showed a general increase with depth in the ill-drained podzols. The mean values of these ratios are shown in Table 4. It would appear from these results that these ratios might be used for differentiation at the soil group level but further confirmatory work is desirable.

TABLE 4.—MEAN VALUES OF THE MOLAR SILICA-SESQUIOXIDE RATIOS

Horizon	Podzols		Brown podzolic		Ill-drained podzols	
	$\frac{SiO_2}{Fe_2O_3}$	$\frac{SiO_2}{Al_2O_3}$	$\frac{SiO_2}{Fe_2O_3}$	$\frac{SiO_2}{Al_2O_3}$	$\frac{SiO_2}{Fe_2O_3}$	$\frac{SiO_2}{Al_2O_3}$
A_0	.11	.16	.19	.23	.12	.10
A_2	.40	.55	.16*	.17*	.32	.27
B_1	.18	.15	.16	.14	.51	.48
B_2	.91	.34	.24	.19	—	—
C	1.29	.45	.40	.48	.63	.77

* Berkshire soils only.

As a rule, the greatest amount of oxalate-soluble manganese was found in the surface horizons, A_0 or A. Generally, the amount of this component in the extracts obtained from the C horizons was equal to or greater than that in the extracts obtained from the corresponding B horizons. The

mean, minimum and maximum values for extractable manganese, expressed as percentage of Mn_3O_4 removed from the soil, are tabulated below.

	A_0	A_2	B or B_1	B_2	C
Mean	.550	.009	.017	.024	.027
Minimum	.002	.000	.001	.011	.010
Maximum	.150	.037	.039	.039	.052

Since the quantities of oxalate-soluble iron, aluminium, titanium and phosphorus showed similar profile distributions they will be considered simultaneously. Of these four elements iron was considered to show the most characteristic distribution in the profiles of the soils examined. That is, the data for extractable iron accorded best with the generally-accepted picture of distribution under podzolization. Nevertheless, the quantities of all four of these elements extracted from the different horizons of the podzol profiles followed the same pattern. Thus, all were present in but small amounts in the A_2, in considerably greater amounts in the B_1, and in decreasing amounts in the B_2. The pattern in the podzolic profiles was similar although the increase of soluble iron and aluminium in the B horizons was less marked. The ill-drained podzols, however, exhibited quite a different picture in this respect, as may be seen by reference to Table 5. In this table the mean values for the amounts of the four elements under consideration which were found in the extracts are given.

TABLE 5.—MEAN VALUES FOR OXALATE-SOLUBLE IRON, ALUMINIUM, PHOSPHORUS AND TITANIUM EXPRESSED AS PERCENTAGE OF DRY SOIL

Component	Horizon	Podzols	Brown podzolic	Ill-drained podzols
Fe_2O_3	A_0	.64	.77	.86
	A_2	.16	.26*	.36
	B_1	3.02	1.13	.20
	B_2	.75	.84	—
	C	.27	.31	.16
Al_2O_3	A_0	.29	.46	1.56
	A_2	.07	.47*	.27
	B_1	1.58	1.11	.13
	B_2	1.43	.70	—
	C	.38	.25	.08
P_2O_5	A_0	.086	.118	.206
	A_2	.017	.039*	.053
	B_1	.081	.083	.041
	B_2	.068	.073	—
	C	.038	.047	.050
TiO_2	A_0	.080	.124	.148
	A_2	.020	.071*	.052
	B_1	.147	.149	.033
	B_2	.082	.130	—
	C	.050	.035	.012

* Berkshire soils only.

The results for phosphorus suggested that the Tamm reagent was a comparatively good solvent for the compounds of this element present in these acid soils. The percentage of the total phosphorus extracted from the various horizons of two of the profiles under study is shown in Table 6

along with the percentage of phosphorus in organic combination as determined by Cann (1). Comparison of the values indicates that the Tamm reagent extracts both inorganic and organic compounds of phosphorus. This is evident when it is noted that 58.7% of the total phosphorus of the Magog A_0 horizon is oxalate-soluble whereas only 20% is inorganic, and that 28.2% is extracted from the Magog B horizon which contains only 3% of organic phosphorus.

TABLE 6.—PERCENTAGE OF TOTAL PHOSPHORUS, A, EXTRACTED BY THE TAMM REAGENT, B, PRESENT IN ORGANIC COMBINATION

Soil type	Horizon	A	B
Ascot sandy loam (Podzol)	A_0	33.9	58
	A_2	10.0	49
	B_1	39.4	42
	B_2	37.7	19
	C	27.7	4
Magog stony loam (ill-drained podzol)	A_0	58.7	80
	A_2	18.5	12
	B	28.2	3
	C	29.3	5

None of the components of the Tamm extract proved to be a suitable criterion for the differentiation of the soil types examined. The variability within a given soil type was too great. This point is illustrated in Table 7, which gives the extractable iron contents of the individual profiles examined.

TABLE 7.—OXALATE-SOLUBLE IRON EXPRESSED AS PERCENTAGE OF Fe_2O_3, REMOVED FROM THE SOIL

Soil	A_2	B_1	B_2	C
Ascot sandy loam	.40	2.30	.65	.25
	.03	4.64	.64	.20
Greensboro loam	.13	2.28	.62	.36
	.10	1.18	1.35	.33
Greensboro loam, rolling phase	.05	3.93	.89	.12
	.23	3.69	.36	.33
Berkshire loam	.28	1.43	.87	.50
	.24	1.20	.90	.35
Woodbridge loam	—	.80	.68	.23
	—	1.09	.90	.16
Magog stony loam	.18	.11	—	.27
	.24	.33	—	.08
Brompton stony loam	.91	.28	—	.16
	.32	.18	—	.22
	.14	.07	—	.09

Examination of this table shows, for example, that on the basis of the oxalate-soluble iron in the B horizons Ascot soils might be confused with Greensboro soils, Greensboro with Berkshire, and Magog with Brompton.

The data for the other components of the extracts were equally inefficient in providing a basis for differentiation at the soil type level. The magnitude of the variability among replicate profiles which is illustrated in Table 7 indicates that it is not practicable to obtain such differentiation by studying larger numbers of profiles of these soil types.

SUMMARY

An attempt has been made to apply the acid ammonium oxalate extraction method of Tamm to the differentiation of soil types. Duplicate, in one instance triplicate, profiles of 7 soil types of podzolic origin were examined. The amounts of silicon, manganese, iron, aluminium, phosphorus and titanium extracted were determined.

The results obtained indicated that the Tamm method is incapable of providing criteria for the differentiation of podzol or podzolic soils at the soil type level.

The Tamm reagent proved to be a comparatively good solvent for the phosphorus compounds in these podzolized soils. It is capable of extracting both organic and inorganic compounds of phosphorus.

REFERENCES

1. Cann, D. B. Acid solubility of inorganic phosphates in Quebec soils. M.Sc. Thesis, McGill University, 1940.
2. Cann, D. B. and P. Lajoie. Soil survey of Stanstead, Richmond, Sherbrooke and Compton counties. Dom. Dept. of Agr. Tech. Bul. 45. 1942.
3. Dyer, W. J. and W. D. McFarlane. A study of the iron in a podzol soil by means of an improved dipyridyl method. Can. J. Res. B, 16 : 91. 1938.
4. Dyer, W. J. and C. L. Wrenshall. An improved method for the determination of phosphate by photoelectric colorimetry. Can. J. Res. B, 16 : 97. 1938.
5. Hillebrand, W. F. and G. E. F. Lundell. Applied Inorganic Analysis. J. Wiley and Sons, New York. 1929.
6. Hoon, R. C. The distribution of sesquioxides, silica and organic matter in forest soil profiles of the Kulu Hill area. Indian Forest Records, n.s., Silvicultural Series, 1 : 347. 1936.
7. Lundblad, K. Studies on podzols and brown forest soils. I. Soil Science, 34 : 137. 1934.
8. Richards, B. Colorimetric determination of manganese in biological material. Analyst 55 : 554. 1930.
9. Tamm, O. Eine Methode zur Bestimmung der Anorganischen Komponenten des Gelkomplexes in Boden. Meddel. Stat. Skogsforsoksanst. (Sweden), 19 : 385. 1922. Cited by Lundblad (7).

A STUDY OF THE VARIABILITY OF CERTAIN CHEMICAL PROPERTIES IN SOILS[1]

A. J. MacLean[2] and R. Summerby[3]

Macdonald College, Quebec

Soil heterogeneity as reflected in yields of experimentally grown crops has been noted by agronomists for many years. Harris and Scofield (7), Garber and Hoover (6) have shown the permanence of differences in experimental plots over a period of years. This would seem to indicate that in many cases at least, heterogeneity in crop yields is not due to transient effects of previous crops, but to real differences in the soil itself. While soil chemists too have been aware of soil variability, and have considered it in relation to soil sampling, in the main it has not been given the same attention accorded it by agronomists.

The Macdonald College Soil Fertility Committee has carried on during the past few years, soil fertility studies on farms in the region of Sawyerville, Compton County, Quebec. In 1937 and 1938 when new areas were selected for this work, it was deemed advisable to obtain some information on the uniformity of these areas in respect to chemical properties. Such information should be suggestive of how intensive a sampling procedure should be, to represent adequately the soils of this region. It should also throw some light on how suitable such areas as those selected are for experimental purposes, and should provide some guidance in the selection of plots from experimental areas for chemical studies. While the results to be presented cannot be applied in full to other areas, they do indicate the degree, and to some extent the pattern, of soil variability that may be encountered.

REVIEW OF LITERATURE

It is to be expected in cases where row applications of fertilizers have been made in large amounts, that the soil will have been made variable. This is shown in the studies of Horton and Stinson (8) where it was found that the residual effects of fertilizer application to tobacco soils presented a sampling problem. Again, a constituent such as nitrate would be expected to be variable. This has been shown to be true in investigation by Waynick (17), Prince (11), Karraker (9), and Blaney and Smith (2).

It is of interest to note the variation in chemical properties which has been found to exist in what were considered to be uniform fields. Robinson and Lloyd (12) were among the first to make a study of the magnitude of field sampling errors due to the variability in the soil from point to point, where samples are taken. Phosphoric acid and organic matter estimates on 15 borings from a field of uniform appearance, indicated the field errors of a boring to be of greater magnitude than the laboratory errors.

[1] Contribution from the Faculty of Agriculture, McGill University, Macdonald College, Que., Canada. Macdonald College Journal Series No. 194 representing a part of a M.Sc. thesis presented at McGill University by A. J. MacLean. Presented before a meeting of the Soils Group of the Canadian Society of Technical Agriculturists at Toronto, June 27-29, 1944.

[2] Formerly Graduate Assistant in Soil Fertility, Macdonald College, now employed with Canadian Defence Industries Ltd., Nitro, Que.

[3] Professor and Chairman of Department of Agronomy.

Bear and McClure (1) determined the total nitrogen content of 45 borings taken to depth of $6\frac{2}{3}$ inches in case of surface samples, and from $6\frac{2}{3}$ to $13\frac{1}{3}$ inches in case of subsurface samples, from a 1/20-acre plot chosen for its uniformity. The nitrogen content varied from 0.118 to 0.243% in subsurface soil.

Waynick and Sharp (18) determined total nitrogen and carbon of 100 borings taken to a depth of 1 foot from each of two areas about 1.1 acres in size, selected for their uniformity. The field sampling errors exceeded the laboratory errors. In the case of one of the areas, the coefficient of variability for nitrogen, as well as for carbon, was found to be 9.00%. In the other area the coefficients of variability were 21.87 and 25.11% for nitrogen and carbon, respectively.

Frear and Erb (5) employed three methods in sampling two one-eighth-acre plots. Loss on ignition, nitrogen, potassium and phosphoric acid were determined. They report that despite unusual care, the sampling error remains greater than laboratory error.

Prince (11) determined in duplicate the total nitrogen content of each of 25 samples distributed over each of three plots which had received different treatments for a period of years prior to sampling. The coefficient of variability of the field samples was higher than that estimated from laboratory duplicates, in the case of each plot. However, the plots were found to be relatively uniform, the highest coefficient of variability being 5.57%.

Collins and Hodgen (3) studied variability of soils represented at five locations serving as sites for peanut production in North Carolina. A composite sample of 9 borings was taken from each 1/50-acre plot. On 144 plots at each location, tests for potassium, magnesium, calcium, phosphorus and pH were made by Hester's method, slightly modified. Considering that the fields were selected as uniform, the variations suggest necessity of careful sampling.

Youden and Mehlich (20) report a study of the variability of two soils not under cultivation, and representative of soils which might be studied in a soil survey in determining a soil type. Samples were taken at distances of 10 feet, 100 feet, 1000 feet and 1 to 3 miles, and pH determined. They conclude that intervals of 10 or 100 feet are too small for effective sampling.

MATERIALS AND METHODS

The studies to be reported are based on soils of experimental plots on each of four farms, in the Eastern Townships region of Quebec. These farms are designated as the B, McK, H and M farms, and they are located in the vicinity of Sawyerville, Quebec.

A description of the soils of this region may be obtained from the Soil Survey report of the area (13). All the experimental areas are located in the podzol zone on what has been mapped as a Greensboro loam. It is reported that the underlying formation is Ordovician black and grey slates and interbedded limestones, with some schistose material. The parent material is of glacial till, and contains impure limestone and slate. The drainage is reported to be good.

From observation the selected farms would appear to be typical of the region, and the usual rotation is a crop of oats, followed by hay crops, until yields become unduly low. The chief fertilizer application has been farmyard manure. All the experimental areas are located on a gentle slope. At time of selection each area was in sod, and all were ploughed and disced before sampling. From within duplicate blocks on each area, 7 plots were chosen at random from 21 plots comprising a block. Each selected plot was divided into halves, and these two half-plots constituted the units sampled for soil variability studies. On the B and McK farms the plots are 13 feet $\times$ 16.75 feet, and are separated by 2 ft. alleys. On the H and M farms, the plots are 10 feet $\times$ 20 feet, and are separated by 3 ft. alleys. Following plowing and discing of the soil, a composite sample was taken from each half-plot. On the B and McK areas sampled in October 1937, each composite consisted of 8 uniformly distributed spade slices of soil to plough depth. In the case of the H and M areas, sampled in October 1938, each composite consisted of 6 uniformly distributed borings to plough depth, taken with a soil sampling tube $1\frac{3}{4}''$ in diameter.

As a measure of soil variability, the following analyses were made: pH, total nitrogen, easily oxidizable carbon, exchangeable potash, and easily soluble inorganic phosphorus. Measurements of pH were made by means of a Hellige pH meter, provided with a glass electrode, on 1-1 suspension of soil according to *Methods of Analysis* (10). Total nitrogen was determined by the Gunning-Hubbard method as outlined in *Methods of Analysis* (10). Carbon was determined by the method of Thomas and Williams (14), excepting that weighed 5-gram samples were used. In the determination of exchangeable potash, extraction and preparation for the estimation were done according to the method of Volk and Truog(16). The determination was completed as directed by Wilcox (19), the volumetric procedure being used. Easily soluble phosphorous was determined by the method of Truog (15) the readings being made visually with a Kennicott-Campbell-Hurley calorimeter. In the determination of pH with the method employed, the greatest discrepancy in readings on the same sample has been 0.05 pH unit. Single determinations only of pH were made. All other analyses were performed in duplicate.

DISCUSSION OF RESULTS

General Variability

The variation resolves itself into the following categories: variation between farms, variation between blocks within farms, variation between plots within blocks, variation between the halves of each plot, and where duplicate laboratory determinations were made, the variation between these duplicates, designated as subsamples. It is believed that a comparison of the sources of variation will give a picture of the nature of variability present.

The detailed analytical results are given in Appendix Tables I and II. These data have been treated statistically by means of the analysis of variance of Fisher (4). In making comparisons, F values are used. In Table 1 the variances for the sources of variation are given for each constituent, comparisons being made between variances in brackets.

TABLE 1.—COMPARISON OF SOURCES OF VARIABILITY OF CONSTITUENTS STUDIED

Sources of variation	D.F.	pH variance	Total N. variance	Easily oxid. C variance	Exchange-able potash variance	Easily sol. inorg. phosphorus variance	F. value required P : .05	P : .01
Between Farms	3	1.5781	0.026548	2.253	25811.2	23696.3		
Between Blocks within farms	4	0.0587 †	0.000723 †	0.1077 †	2280.5 *	74.0 †	6.59	16.69
Between Plots within blocks	48	0.0891	0.002048	0.3265	1586.3	74.5	2.56	3.74
Between Half-plots within plots	56	0.0056 †	0.000549 †	0.0944 †	803.8 †	28.6 †	1.58	1.90
Between Subsamples within half-plots	112	—	— 0.000007 †	0.0046 †	19.5 †	4.3 †	1.48	1.73

* Significant difference.
† Highly significant difference.

From Table 1, the following observations may be noted:

(1) There is greater variation between experimental areas on the different farms than within these areas in respect to all constituents considered. Although seasonal effect is confounded with the differences between farms, it is not considered to alter the general conclusion since it was found that farms sampled in the same year showed appreciable differences. Constituents such as total nitrogen and easily oxidizable carbon would not be expected to show measurable differences within the period in question.

(2) With the arrangement of blocks and plots employed, the variation between blocks was not shown to be different from the variation between plots within the blocks. An examination of the data of the individual farms involved in Table 1, however, showed that this did not hold true for the B farm in respect to phosphorus and potash, nor for the McK farm in respect to phosphorus in which cases the block variances exceeded the plot variances, using the .05 point. With reservation because of the exceptions noted, it may be stated that with the block and plot arrangement used, no appreciable gradient in respect to the content of the various constituents was found within the experimental area of each farm studied, as measured by the plot variances.

(3) There is greater variation between plots than between the halves of these plots in respect to all constituents studied. Considering the farms individually this did not apply in the case of the B farm in respect to nitrogen and carbon, nor in the case of the H, McK and M farms in respect to potash, although the latter two farms showed a trend in support of the general conclusion. It would seem in general that the soil variability studied here follows a random pattern, giving rise to appreciable differences between plots within the same block as measured by the half-plot variances. From the smaller half-plot variances it would appear that within limited areas such as those of the plots employed, less soil variability occurs.

(4) The invariably high half-plot variances as compared to subsample variances suggest soil variability as an important source of error in soil investigations.

TABLE 2.—STANDARD ERRORS OF A SINGLE PLOT WITHIN A BLOCK AND MEANS FOR VARIOUS CONSTITUENTS

Farms	D.F.	P.H.		Total nitrogen		Easily oxid. carbon		Exchangeable K_2O per acre		Easily soluble inorg. P_2O_5 per acre	
		S.E.	Means	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean
				%	%	%	%	lb.	lb.	lb.	lb.
B	12	0.16	4.98	0.033	0.263	0.45	3.62	40.9	133.0	5.0	32.0
McK	12	0.17	5.05	0.033	0.303	0.55	3.68	58.8	96.0	5.8	34.0
H	12	0.21	4.87	0.031	0.309	0.29	3.27	30.2	95.0	6.5	37.0
M	12	0.51	5.42	0.071	0.306	0.85	3.34	17.2	85.0	53.6	75.0
All farms	48	0.30	5.08	0.045	0.295	0.57	3.48	39.8	102.0	27.3	45.0

Variation between Plots within a Block

In field experimentation, the precision is determined by the error to be associated with an individual plot. This error may be calculated from the plot variances of each farm, for each constituent considered. In Table 2 the standard errors to be associated with single plots within a block for each farm, and for the farms considered together, along with appropriate plot means are given for each constituent studied. These errors are made up of the error between plots within a block, the errors of soil sampling, and the laboratory errors. However, as the sampling for each plot consisted of 8 spade slices in the case of the B and McK farms, and 6 borings in the case of the H and M farms, from each half of the plot, it may be stated that the sampling has been fairly intensive. The laboratory errors are seen to be small, as revealed by the small subsample variances in Table 1.

It will be noted from Table 2 that the plots are subject to appreciable errors. The magnitude of these errors may be appreciated by referring them to the means of the different constituents, which are estimates of the amount of any constituent which a single plot may be expected to contain. The high variability of the area on the M farm in respect to all constituents except exchangeable potash suggests that this area is too variable for the purposes of experimentation. The relatively low plot error for the M farm and the high plot errors for the B and McK farms in respect to exchangeable potash, would seem to indicate that in this region exchangeable potash cannot be used as a criterion of general variability of the soil.

Following different treatments it is often desirable to measure and to compare the relative levels of a chemical constituent in the soil. From the Standard Errors in Table 2, the differences required for significance between means of any number of plots may be computed for each constituent. In Table 3, the differences required for significance between means of 2, 4, 6 and 8 replicate plots are given for each farm, and on the

TABLE 3.—DIFFERENCES REQUIRED FOR SIGNIFICANCE BETWEEN MEANS OF 2, 4, 6 OR 8 REPLICATE PLOTS FOR VARIOUS CONSTITUENTS WHEN P = .05

Farm	Number of plots in mean	pH	Total nitrogen	Easily oxid. carbon	Exchange-able K_2O per acre	Easily soluble inorg. P_2O_5 per acre
			%	%	lb.	lb.
B	2	0.31	0.066	0.90	81.8	10.0
	4	0.22	0.048	0.64	57.8	7.0
	6	0.18	0.040	0.50	47.2	5.6
	8	0.16	0.034	0.45	41.0	5.1
McK	2	0.34	0.066	1.10	117.6	11.6
	4	0.22	0.048	0.78	83.2	8.2
	6	0.20	0.040	0.62	68.0	6.8
	8	0.17	0.034	0.54	58.8	5.9
H	2	0.42	0.062	0.58	60.4	13.0
	4	0.32	0.046	0.42	42.8	9.2
	6	0.24	0.036	0.34	34.8	7.6
	8	0.21	0.031	0.28	30.2	6.5
M	2	1.02	0.142	1.70	34.4	107.2
	4	0.70	0.102	1.20	24.4	75.8
	6	0.60	0.082	1.00	19.8	62.0
	8	0.51	0.070	0.85	17.2	53.7
All farms	2	0.60	0.090	1.14	61.6	54.6
	4	0.42	0.064	0.82	43.6	38.6
	6	0.34	0.050	0.64	35.6	31.4
	8	0.31	0.045	0.56	30.8	27.4

basis of all farms for each constituent considered. On the basis of the areas studied and with the method of sampling employed, small differences following treatments could not be assumed to be real. But it may be assumed that only 5 out of 100 times would differences exceeding those given in Table 3 occur by chance. The effectiveness of replication in increasing the accuracy of experiment, so that smaller differences due to treatment may be measured, is illustrated.

In the designing of an experiment to measure the effects of different treatments, the question arises as to how many replicate plots are required. The number will depend on the variability of the soil, the size of the differences it is desired to measure, and the probability we are willing to accept that our differences are real and not due to chance. For the area studied the number of replicate plots required to measure any desired difference may be calculated from the errors in Table 2, for any of the constituents considered. For example, if following treatments it is desired to make comparisons of the nitrogen content of plots and to detect differences as small as .030%, the number of plots required on the basis of the plot error for all farms (± .045%) is found to be 18. Only 5 out of 100 times would a difference between means of 18 replicate plots, exceeding .030%, occur by chance.

It is believed that the observations made are at least suggestive of the importance of certain factors relative to field technique in chemical studies of soils.

SUMMARY AND CONCLUSIONS

The variability of pH, total nitrogen, easily oxidizable carbon, exchangeable potash and easily soluble inorganic phosphorus was investigated on experimental areas on each of four farms in the Eastern Townships of Quebec. Analyses for the above constituents were made on composite samples from each half of 7 random plots, from each of two blocks on each farm.

With the arrangement of blocks and plots employed, the variation between blocks was not shown to be different from the variation between plots within the blocks. It would appear that no definite gradient exists across these experimental areas.

On the basis of all farms, the standard errors of single plots for pH, percentage total nitrogen, percentage easily oxidizable carbon, exchangeable potash (lb. K_2O per acre) and easily soluble inorganic phosphorus (lb. P_2O_5 acre), were found to be 0.30, 0.045, 0.57, 39.8 and 27.3, respectively. The differences required for significance between means of 2, 4, 6 or 8 replicate plots were calculated for each constituent. It was shown that following treatment small differences could not be assumed to be real. The effectiveness of replication in increasing the accuracy of an experiment so that smaller differences could be measured was illustrated.

The significantly higher half-plot variances as compared to those computed from duplicate laboratory determinations, indicates that attention should be given to sampling of soils for chemical studies.

Realizing the complexity of soil variability and that only the ploughed layer has been studied, as well as the fact that a number of factors give rise to variable stands on plots treated alike, it is not supposed that results from chemical studies will parallel those of uniformity trials. However, some correlation is expected. The studies reported have indicated the M farm to be especially variable. This was borne out in marked irregularities which occurred in stands of clover on this experimental area. It would appear that studies of the sort reported afford a means of eliminating areas unsuitable for soil fertility studies.

ACKNOWLEDGMENTS

Appreciation is expressed to Dr. W. A. DeLong for guidance in connection with the chemical aspects of this problem, and to H. F. Salisbury who performed a number of the analyses for nitrogen.

REFERENCES

1. Bear, F. B. and G. M. McClure. Sampling soil plots. Soil Sci. 9 : 65. 1920.
2. Blaney, J. E. and J. B. Smith. Sampling market-garden soils for nitrates. Soil Sci. 31 : 281. 1931.
3. Collins, E. R. and W. R. Hodgen. Field variation as a factor in sampling for rapid soil analyses. Assoc. Southern Agr. Workers. Proc. Ann. Meeting 41 : 77. 1940.
4. Fisher, R. A. Statistical Methods for Research Workers. Oliver and Boyd, Edinburgh. 1936.
5. Frear, W. and E. S. Erb. A study in soil sampling. Journ. A.O.A.C. 4 : 98. 1920.
6. Garber, R. J. and M. M. Hoover. Persistence of soil differences with respect to productivity. Jour. Amer. Soc. Agron. 22 : 883. 1930.

REFERENCES—*Concluded*

7. Harris, J. A. and C. S. Scofield. Permanence of differences in the plots of an experimental field. Jour. Agr. Research 20 : 335. 1920.
8. Horton, H. A. and F. A. Stinson. Investigations in sampling soils previously fertilized for flue-cured tobacco. Sci. Agric. 19 : 616. 1939.
9. Karraker, P. E. The variable occurrence of nitrates in soils. Soil Sci. 24 : 259. 1927.
10. Methods of Analysis of the Association of Official Agricultural Chemists. (5th ed.). 1940.
11. Prince, A. L. Variability of nitrates and total nitrogen in soils. Soil Sci. 15 : 395. 1923.
12. Robinson, G. W. and W. E. Lloyd. On the probable error of sampling in soil surveys. J. Agr. Sci. 7 : 144. 1915.
13. Cann, D. B. and P. Lajoie. Soil Survey of Stanstead, Richmond, Sherbrooke and Compton Cos., Que. Dom. of Can. Tech. Bul. 45. 1942.
14. Thomas, R. P. and R. C. Williams. A comparison of the results of rapid tests with the amounts of available nutrients obtained by quantitative methods on Maryland soils. Soil Sci. Soc. of Amer., Proc. 1 : 243. 1936.
15. Truog, E. The determination of the readily available phosphorus of soils. Jour. Amer. Soc. Agron. 22 : 874. 1930.
16. Volk, N. J. and E. Truog. A rapid chemical method for determining the readily available potash of soils. Jour. Amer. Soc. Agron. 26 : 537. 1934.
17. Waynick, D. D. Variability in soils, and its significance to past and future soil investigations. 1. A statistical study of nitrification in soil. Univ. Calif. Pub. Agric. Sci. 3 : 243. 1918.
18. Waynick, D. D. and L. T. Sharp. Variability in soils and its significance to past and future soil investigations. II. Variations in nitrogen and carbon in field soils and their relation to the accuracy of field trials. Univ. Calif. Publ. Agric. Sci. 4 : 121. 1919.
19. Wilcox, L. V. Determination of potassium. Ind. and Eng. Chem., Anal. Ed. 9 : 136. 1937.
20. Youden, W. J. and A. Mehlich. Selection of efficient methods for soil sampling. Contrib. Boyce Thompson Inst. 9 : 59. 1937.

APPENDIX

TABLE I.—ANALYSES OF SAMPLES FROM B AND McK FARMS FOR pH, TOTAL NITROGEN, EASILY OXIDIZABLE CARBON, EXCHANGEABLE POTASH AND EASILY SOLUBLE INORGANIC PHOSPHORUS

—	Plot	pH		Total N (%)				Easily oxid. C (%)				Exchangeable potash (lb. K_2O per acre)				Easily sol. inorg. phosphorus (lb. P_2O_5 per acre)			
		Half-plot A	Half-plot B	Half-plot A		Half-plot B		Half-plot A		Half-plot B		Half-plot A		Half-plot B		Half-plot A		Half-plot B	
				Orig.	Dup.	Orig.	Dup.	Orig.	Dup.	Orig.	Dup.	Orig.	Dup.	Orig.	Dup.	Orig.	Dup.	Orig.	Dup.
B FARM:																			
Block 1	2	5.00	5.05	.221	.221	.260	.265	3.12	3.18	3.79	3.73	161	155	143	148	34	33	32	33
	4	5.10	5.05	.227	.228	.267	.270	3.34	3.34	3.92	4.04	180	187	173	160	28	28	28	27
	8	4.90	4.90	.258	.260	.290	.287	3.73	3.40	3.73	3.83	147	148	144	142	34	36	38	39
	9	4.85	4.89	.266	.262	.245	.248	3.86	3.76	3.52	3.46	144	136	132	139	30	31	26	29
	13	4.95	4.95	.289	.291	.251	.249	3.67	3.73	3.09	3.27	139	132	108	114	31	30	30	32
	17	5.05	4.95	.276	.280	.290	.293	4.04	3.98	4.59	4.31	167	170	137	145	27	25	31	29
	21	5.00	5.05	.219	.218	.277	.280	3.12	3.12	3.89	3.86	142	139	123	120	28	30	32	34
Block 2	4	5.25	5.10	.224	.227	.274	.277	3.24	3.37	3.95	3.89	87	95	105	97	34	36	36	34
	5	4.95	5.05	.249	.250	.238	.238	3.61	3.49	3.61	3.70	156	138	146	138	28	30	33	36
	7	5.00	4.90	.291	.291	.273	.274	3.76	3.73	3.73	3.83	167	167	145	166	31	32	31	34
	9	4.90	4.80	.287	.291	.270	.269	3.76	3.83	3.70	3.76	116	113	139	131	32	32	36	33
	13	4.80	5.10	.231	.237	.293	.296	3.18	3.09	3.83	3.89	88	93	129	138	36	33	37	36
	16	4.85	4.85	.280	.276	.290	.291	3.61	3.64	3.58	3.52	100	98	108	119	37	34	34	34
	19	5.15	5.20	.260	.262	.241	.241	3.24	3.40	3.21	3.34	113	100	105	109	36	40	32	31
McK FARM:																			
Block 1	1	4.85	4.95	.314	.317	.329	.328	3.70	3.83	3.92	3.83	129	131	110	116	38	38	41	38
	2	5.05	5.20	.300	.295	.318	.318	3.89	3.79	3.89	4.01	105	117	63	71	32	34	34	38
	4	5.10	5.00	.298	.299	.311	.311	3.86	3.89	3.76	3.86	93	87	113	113	28	30	31	31
	11	4.90	4.96	.309	.307	.344	.343	3.86	3.89	4.31	4.22	116	110	91	79	41	37	38	34
	17	4.85	5.15	.314	.314	.284	.288	3.73	3.83	3.18	3.18	116	103	88	93	40	43	38	40
	18	4.80	4.95	.314	.308	.291	.290	3.86	3.79	3.30	3.21	105	101	98	96	40	38	31	34
	21	5.20	5.25	.304	.302	.300	.300	3.61	3.70	3.61	3.64	74	68	105	102	33	34	28	31
Block 2	1	4.90	5.00	.284	.286	.279	.277	3.16	3.34	3.24	3.34	94	90	91	84	36	34	36	32
	6	5.10	5.15	.286	.287	.283	.283	3.55	3.61	3.18	3.30	112	111	255	243	31	29	32	30
	7	5.25	5.25	.301	.307	.269	.270	3.09	3.12	3.83	3.83	70	67	71	70	32	31	33	34
	18	5.05	5.05	.301	.304	.302	.302	3.70	3.64	3.70	3.67	71	72	70	72	30	30	31	30
	19	4.95	5.00	.297	.294	.304	.300	3.43	3.40	3.49	3.55	98	106	79	76	38	34	33	31
	20	5.15	5.20	.273	.277	.288	.293	3.58	3.61	3.37	3.46	73	71	56	63	31	31	30	31
	21	5.25	5.00	.344	.344	.339	.336	4.35	4.31	4.25	4.35	81	73	75	78	33	34	31	30

APPENDIX—Concluded

TABLE II.—ANALYSES OF SAMPLES FROM H AND M FARMS FOR pH, TOTAL NITROGEN, EASILY OXIDIZABLE CARBON, EXCHANGEABLE POTASH AND EASILY SOLUBLE INORGANIC PHOSPHORUS

—	Plot	pH		Total N (%)				Easily oxid. C (%)				Exchangeable potash (lb. K_2O per acre)				Easily sol. inorg. phosphorus (lb. P_2O_5 per acre)			
		Half-plot A	Half-plot B	Half-plot A		Half-plot B		Half-plot A		Half-plot B		Half-plot A		Half-plot B		Half-plot A		Half-plot B	
				Orig.	Dup.	Orig.	Dup.	Orig.	Dup.	Orig.	Dup.	Orig.	Dup.	Orig.	Dup.	Orig.	Dup.	Orig.	Dup.
H FARM:																			
Block 1	4	4.85	4.90	.323	.324	.324	.324	3.34	3.24	3.49	3.70	81	86	94	105	34	36	31	36
	6	4.90	4.85	.323	.319	.318	.323	3.55	3.64	3.27	3.37	100	100	90	91	34	38	36	38
	7	4.80	4.85	.308	.309	.306	.305	3.21	3.12	3.30	3.21	84	77	84	84	38	34	32	33
	8	4.95	4.95	.288	.287	.306	.312	3.00	2.94	3.27	3.15	87	94	97	103	34	36	36	38
	10	5.20	5.25	.291	.290	.314	.309	3.12	3.00	3.15	3.12	86	87	161	162	38	41	40	41
	14	5.00	4.80	.265	.268	.287	.280	3.12	3.03	3.27	3.37	77	77	96	103	41	39	35	38
	20	4.80	5.00	.308	.306	.336	.337	3.34	3.34	3.52	3.55	87	89	110	113	36	38	40	41
Block 2	1	5.15	5.15	.296	.296	.291	.291	3.21	3.06	2.94	2.85	76	70	77	79	34	38	34	35
	4	4.90	4.80	.309	.306	.298	.293	3.30	3.40	3.27	3.15	99	98	84	77	32	33	31	32
	7	4.70	4.70	.301	.297	.304	.306	3.43	3.40	3.21	3.24	78	78	84	80	34	38	34	37
	15	4.80	4.70	.307	.306	.324	.319	3.52	3.43	3.30	3.45	105	98	94	86	33	34	34	36
	16	4.75	4.75	.339	.321	.302	.298	3.27	3.34	3.30	3.34	89	90	89	97	38	39	44	42
	18	4.75	4.70	.323	.327	.350	.334	3.30	3.27	3.27	3.37	93	92	162	163	40	41	45	45
	20	4.75	4.60	.327	.322	.308	.308	3.27	3.27	3.30	3.21	100	95	79	84	40	41	36	38
M FARM:																			
Block 1	1	5.80	5.90	.342	.344	.334	.337	3.89	3.79	3.79	3.76	88	84	80	84	102	107	115	117
	5	5.35	5.35	.244	.247	.288	.282	2.69	2.75	2.97	2.94	78	77	75	77	48	53	49	53
	11	5.30	5.40	.318	.317	.322	.322	3.27	3.34	3.40	3.46	89	95	100	99	76	77	60	62
	13	5.05	5.05	.310	.310	.292	.290	3.00	2.88	3.18	3.18	82	82	74	69	59	56	52	50
	15	6.30	6.35	.344	.348	.386	.380	3.89	3.73	4.10	4.01	78	84	98	96	143	130	137	146
	19	5.20	5.35	.278	.279	.282	.285	3.18	3.18	2.97	2.94	72	72	89	84	51	55	60	62
	21	5.00	5.10	.293	.294	.283	.282	3.09	3.12	3.18	3.21	79	80	83	88	45	44	45	43
Block 2	4	5.25	5.25	.302	.303	.290	.289	3.27	3.27	3.06	3.18	92	90	72	74	71	71	76	71
	5	5.30	5.20	.272	.269	.274	.269	2.97	3.00	2.88	2.75	77	82	86	80	88	89	76	69
	16	5.75	5.80	.360	.356	.355	.357	3.98	3.95	4.01	4.01	103	100	79	75	96	103	96	102
	17	5.35	5.50	.343	.346	.352	.354	4.01	3.92	3.98	3.98	115	121	100	92	66	64	73	73
	18	5.50	5.45	.300	.294	.316	.313	3.18	3.37	3.34	3.46	82	89	71	77	61	64	64	66
	20	5.25	5.25	.263	.260	.277	.273	2.94	3.00	3.12	3.06	85	88	89	79	60	59	68	66
	21	5.15	5.20	.288	.288	.274	.271	3.21	3.24	3.15	3.15	79	81	77	74	71	75	90	92

RAPID SOIL TESTS ON SOME CARLETON COUNTY SOIL[1]

H. J. ATKINSON[2], P. O. RIPLEY,[3] AND L. M. PATRY[4]

The county of Carleton in the Province of Ontario has an estimated land area of 585,600 acres. The soil survey mapped 25 different soil groups, comprising 37 soil types. The eleven largest groups being farmed together make up nearly 75% of the total land area (Table 1). Muck and peat soils cover an area of 60,480 acres. Granby sand and sandy loam occupy 13,760 acres, but little of this is farmed.

Since the soil survey was made in 1941, certain lines of investigation have been carried out in connection with some of the major soil types with a view to learning something about their relative present and potential fertility levels as well as the adaptation of different field crops for growth on these soils. This work has been conducted by the Division of Field Husbandry, Experimental Farms Service, with collaboration by the Division of Chemistry, Science Service, wherever chemical studies were required.

Soil samples from the eleven types listed in Table 1 were brought into the greenhouse, placed in glazed pots of 1 gallon capacity and treated with commercial fertilizer of different formulae and at various rates. Samples were obtained from two farms on each soil type in 1941 (only one farm on the Uplands, Grenville and Carp types) and fresh samples were taken in 1942, in most cases from the same farms. An attempt was made to select one farm on each type where the number of head of livestock kept had been relatively high and where fairly large amounts of manure had been returned to the soil, thus presumably raising the fertility level somewhat above the average. The other farm on each soil type was selected where the system of farming did not provide for the keeping of so much livestock and where probably the fertility level was normal or somewhat below normal. The purpose of this selection was to study the effect of two different systems of farm management on the productivity of the various soil types.

The crops grown in the greenhouse were barley followed by red clover in 1941-42, and oats followed by alfalfa in 1942-43. Fertilizer treatments included the following:

1. Check—no treatment.
2. Nitrogen—40 lb. N per acre.
3. Phosphorus—80 lb. P_2O_5 per acre.
4. Potassium—60 lb. K_2O per acre.
5. Nitrogen and phosphorus.
6. Nitrogen and potassium.
7. Phosphorus and potassium.
8. Nitrogen, phosphorus and potassium.

The fertilizer was applied in the form of sulphate of ammonia, superphosphate (20%) and muriate of potash, applied in a layer 1 inch below

[1] Paper presented before the Soils Group of the Canadian Society of Technical Agriculturists in Toronto June 28, 1944. Joint contribution from the Division of Chemistry, Science Service, and the Division of Field Husbandry, Experimental Farms Service. Scientific Contribution No. 116, Division of Chemistry, Science Service.

[2] Associate Chemist, Division of Chemistry.

[3] Assistant, Division of Field Husbandry.

[4] Junior Chemist, Division of Chemistry.

the grain which was seeded 1 inch deep. In 1941-42 one application was made for barley which was grown to maturity. After harvesting the barley, the surface soil was stirred and a second application was put on immediately previous to seeding red clover. The latter was sown ½ inch deep. In 1942-43 only one application was made when seeding oats and alfalfa. The fertilizer was placed in a layer 2 inches from the surface, then 1 inch of soil was replaced and the oats seeded 1 inch deep, then ½ inch of soil was replaced and the alfalfa was broadcast and covered with ½ inch of soil. The oats and alfalfa grew in the same pot in a manner simulating field practice.

Soil samples for laboratory examination were taken from the soils used in the greenhouse work in 1941-42 and also in 1942-43. Thus, in most cases, there were four samples from each soil type. The following determinations were made on the air-dried samples: pH, moisture, loss on ignition, nitrogen, phosphorus, exchangeable lime, magnesia and potash, readily soluble phosphoric acid by the Ruhnke method, rapid tests for lime, magnesia, potash and phosphoric acid on all samples by the Spurway and the Morgan methods, rapid tests for potash and phosphoric acid by the Thornton method on the 1941 samples, and rapid tests for phosphoric acid by the Guelph modification of the Thornton method on the 1941 samples.

The purpose of this paper is to attempt to assess the value of the various rapid methods of soil testing when applied to a series of soil types, of varying texture, and on which several species of crops are grown. To do this, the results of the tests will be discussed in relation to the response to fertilizer applications as measured by the yields of the various crops grown under greenhouse conditions. The tests were applied, without modification, according to the directions given in the methods as published.

The response of the crop to each of the three main fertilizer elements N, P and K has been expressed as a percentage increase in yield due to that element when used alone and with each of the other elements. Thus, for nitrogen, the percentage increase of the N-treated pots over the check was determined, also that for NP over P, for NK over K, and for NPK over PK. The average of these has been taken as a measure of the response to N fertilization. Similar calculations were made for the elements P and K.

In order to give some idea as to the relative productivity of the different soil types, the actual yields in grams per pot obtained from the untreated soils are presented in Table 2.

RESULTS

Uplands Sand

The first soil type to be considered is the Uplands sand, where work was carried out on samples from the J. Stewart farm in both years and from the R. Lecuyer farm in 1942. The response (Table 3) of the cereals to nitrogen was very marked (+ 374% for barley and + 146% for oats on the Stewart soil, + 75% for oats on the Lecuyer soil). The growth of the legumes, however, was apparently depressed by N (− 9% for clover and − 45% for alfalfa on the Stewart soil, − 29% for alfalfa on the Lecuyer soil). The total soil nitrogen was very low (less than 0.1%) on these soils.

The response to phosphorus was much less marked. An increase of 28% on clover on the Stewart soil and 30% on oats on the Lecuyer soil was shown, but in all other cases, although there was an average increase, it was always less than 20% and the individual results showed a wide variation. The rapid soil tests for P showed considerable variation, L-VVL by Spurway's method, MH-L by Morgan's, VH by Thornton's and H by the Guelph modification. The readily soluble P_2O_5 by the Ruhnke method on the Stewart samples was 53 and 80 p.p.m., which was considered to be somewhat low, and, on the Lecuyer soil, 100 p.p.m. which was thought to be adequate.

The response to potassium was not great. Although an average increase of 34% was obtained on clover on the Stewart soil, and 32% on alfalfa on the Lecuyer sample, in all other cases the average increase was less than 12%. Since all rapid soil tests were either low or very low, and the exchangeable potash was very deficient (considerably less than 0.015%), a more general response to potash fertilizers might have been expected.

Rubicon Sand

Samples on this soil type were taken from the Saunders and Hawkins farms. The response (Table 4) of cereals to nitrogen was very good, though less than that obtained on Uplands sand. The average figures are +62% for barley and +25% for oats on the Saunders soil, +58% for barley and +48% for oats on the Hawkins soil. The growth of clover was scarcely affected (−5% in the one case, +3% in the other) though alfalfa gave increases of 26% and 22% on the two soils. The total soil nitrogen was on the low side (between 0.10% and 0.21% on four samples).

Cereals on the Saunders soil showed no definite response to phosphorus (+8% for barley, −2% for oats). On the Hawkins soil, phosphorus gave a 24% increase with barley but a 10% decrease with oats. The results on the legumes were erratic. On the Saunders soil, an 8% decrease with clover and a 24% increase with alfalfa were recorded, but on the Hawkins soil, the results were an 18% increase on clover and a 5% decrease on alfalfa. The rapid soil tests for P again showed a wide variation, L-VL by Spurway's method, M-MH by Morgan's, M-L by Thornton's and H by the Guelph modification. The readily soluble P_2O_5 was low (39-74 p.p.m.) on three soil samples, but quite adequate (128 p.p.m.) on the fourth, the 1942-43 sample from the Hawkins farm. It was difficult to see any relationship here between tests and response to fertilizers.

With one exception (barley on the Saunders soil), there appeared to be a response to potash fertilization on this soil type. The increase is greater on the Hawkins soil than on the Saunders soil and greater with legumes than with the preceding cereals. The most outstanding increases were found with alfalfa, 85% on the Saunders soil and 162% on the Hawkins soil. All rapid soil tests recorded low or very low results, and the amounts of exchangeable potassium indicated a deficiency, so that a response to potash fertilizers was to be expected. However, amounts of exchangeable potassium were lower on the Uplands sand and nothing like the same response was obtained there.

Kars Gravelly Loam

Samples of this soil type were collected from the Redmond farm in both years, from the McMenomy farm in 1941 and from the L. Lecuyer farm in 1942. The response (Table 5) of cereals to nitrogen was very good, the averages ranging from 80% to 171%. On the other hand, there was a consistent decrease in the yield of legumes where nitrogen was applied, particularly in the case of alfalfa on the Lecuyer sample. The total nitrogen of the soil samples was generally low.

The response to phosphorus was almost negligible for all crops, the average figures ranging from − 2% to + 11%. Spurway's test gave low results in all cases, Morgan's, M-MH, Thornton's, H-VH and Guelph, H. The McMenomy sample gave only 46 p.p.m. readily soluble P_2O_5, the Lecuyer sample 283 p.p.m., but neither showed any response to applied phosphorus.

Potassium was considered deficient by all tests. Nevertheless, there was no response by the cereals (−1% to +4 %) to potash fertilization. Alfalfa on both soil samples and clover on the McMenomy sample showed some response (+26% to +44%). A general response was to be expected.

Manotick Sandy Loam

Samples of this soil type were taken from the Lyttle farm in both years, from the McClure farm in 1941 and from the Goodwin farm in 1942. Again, a good response (Table 6) to nitrogen was obtained with cereals, an average of 67% and 39% with barley, 44% and 69% with oats. The legumes, however, did not respond to this treatment, the average results varying from − 2% to + 8%. The total nitrogen of the soil samples was not very high (0.15%–0.19%).

The average increases from phosphorus applied to cereals was less than 20% except with oats on the Lyttle soil where an average increase of 32% was obtained. On the other hand, very good increases (41%–85%) were obtained with legumes as the result of applications of phosphorus except with alfalfa on the Goodwin soil where the average increase was only 4%. Spurway's test (on the 1942-43 samples only) showed low amounts of phosphorus present, none of the others showed any amount higher than medium. The readily soluble phosphorus by the Ruhnke method was less than 65 p.p.m. with the exception of the Lyttle 1942 sample where the result was 222 p.p.m.

With the exception of alfalfa on the Goodwin soil, where potassium gave an average increase of 87%, there was little if any response to applied potash on this soil type. Clover on the Lyttle soil showed an average increase of 18%, but all other increases were less than 10% and a few slight decreases were recorded. All rapid tests gave low or very low readings, and the amounts of exchangeable potassium were generally deficient. A more general response to potash fertilization might have been expected.

Castor Fine Sandy Loam

Soil samples were obtained from the Waddell and Quaile farms. As with the previous soil types, the response (Table 7) of the cereals to nitrogen was quite marked, the increase being 57% and 95% for barley, 11% and

47% for oats. There was no response of the legumes to nitrogen, the results varying from + 4% to − 13%. The total soil nitrogen was 0.20%–0.21% on the Waddell samples, 0.14%–0.18% on the Quaile samples.

The response to phosphorus was extremely good with all crops on the Waddell sample, but particularly so with the oats (+ 154%) and the alfalfa (+ 239%). The response on the Quaile samples was much less marked, being less than 20% except on the clover crop which showed a 49% increase. Soil tests were L-VVL by Spurway's method, L-H by Morgan's, M-H by Thornton's and M-VH by the Guelph procedure. The readily soluble P_2O_5 was very high, 213–345 p.p.m. on the four samples. In general, crop responses showed best agreement with the results by the Morgan method.

Potassium gave some increase on the legume crops, 33% and 42% on clover, 27% and 9% on alfalfa. There was no significant response to potash fertilizers on the cereal crops, results ranging from + 4% to − 5%. Soil tests indicated that there should have been a response to K fertilization, as all rapid tests were low to very low and exchangeable potassium indicated a definite deficiency (all results less than 0.010%).

Farmington Loam

Samples were collected from the Featherstone and Fraser farms. While some response (Table 8) of cereals to nitrogen fertilization was shown, it was not as great as with most of the other types. Barley on the Featherstone soil gave an average increase of 65%, but in the other three cases, the average varied between 12% and 19%. In all cases there was an average decrease of from 2% to 17% in alfalfa yield due to applied nitrogen. The total nitrogen present in this soil type appeared to be satisfactory and varied from 0.20% to 0.34% in four samples.

With the exception of the barley and clover grown on the Feathstone 1941-42 sample, the response of all crops to phosphorus was very good, showing increases of 43% to 140% on the cereals, and 36% to 314% on the legumes. Tests were all low by Spurway's method, L-MH by Morgan's, M-H by Thornton's, and H by the Guelph modification. The amounts of readily soluble P_2O_5 appeared to be very satisfactory, 215 p.p.m. and 268 p.p.m. on the 1941-42 samples, 156 p.p.m. and 140 p.p.m. on the 1942-43 samples. The soil tests on the Featherstone and Fraser 1941-42 samples were almost identical but the Fraser soil gave a good response (+ 77% on barley, + 36% on clover) whereas the Featherstone soil showed practically none (− 7% on barley, + 10% on clover).

Clover showed some response to potassium applications on both soils (40% and 57%) but responses with other crops were small (+ 2% to + 15%). All soil tests, including the determinations of exchangeable K, were low and a good response might reasonably have been expected.

Grenville Loam

Samples were collected from the Dow farm in both years and from the D. M. Stewart farm in 1942. There was some response (Table 9) by cereals to nitrogen applications, the average increases ranging from 26% to 41%, but again the legumes did not respond, there being an average decrease of 17% with alfalfa on the Stewart sample. The total amount of nitrogen in these samples was reasonably good, 0.25% to 0.29%.

Response to phosphorus was good with all crops on the Dow samples, and with alfalfa but not with oats on the Stewart sample. Morgan's test on the three samples were LM, M and MH; the readily soluble P_2O_5 was in the same order, 77, 92 and 121 p.p.m., respectively; and the response to applied P was greatest where the test showed the lowest amount present, and least where the test showed the greatest amount.

Clover on the Dow sample was the only crop to show any response to potassium and the average increase was only 23%. Tests showed this sample to be deficient in potassium. In both 1942-43 samples, the rapid tests gave low (in one case, medium) results but the amounts of exchangeable potassium (0.026% and 0.030%) were considered satisfactory. On neither of these samples was there response to added potassium.

Osgoode Loam

Samples were collected from the Brown and Nixon farms. The cereals responded to applications of nitrogen, the average increases varying from 19% to 58%. No definite response (Table 10) to nitrogen was observed in the case of the legumes. The 1942 Nixon sample had a very good supply of total nitrogen (0.45%) but the others had considerably less (0.15%–0.21%).

Clover, oats and alfalfa on the Brown soil showed a good response (51% to 86%) to applied phosphorus, but in no other case did the average increase exceed 17%. By Ruhnke's extraction method, these samples seemed to be well supplied with readily soluble P_2O_5, the results varying from 322 p.p.m. to 511 p.p.m. P_2O_5. Spurway's method gave readings from L to M, and Morgan's from M to H. The greatest response to applied P was obtained on the soil which gave a low reading by Spurway's method.

Alfalfa on the Brown samples gave an average increase of 65% when potassium was applied. In the other cases, no average increase was greater than 12%. Rapid soil tests registered VL or L (M by Spurway's method on the Nixon 1942 sample) and determinations of the exchangeable potassium showed that the amounts present were very small (not over 0.005% K_2O). A more general response to potassium fertilization might have been expected.

Carp Clay Loam

Samples were taken from the Ellis & Shaw farm in both years, and from the Hudson farm in 1942. Cereals showed a fairly good response (Table 11) to nitrogen, the averages ranging from 32% to 63%. The response of the legumes to nitrogen varied from − 6% to + 12%. The total amount of nitrogen in the soil samples was reasonably good, from 0.26% to 0.45%.

The legumes on the Ellis & Shaw samples showed good response to phosphorus, particularly alfalfa (+ 90%), but cereals gave no response (− 1% to + 3%). On the Hudson sample, oats gave an increase of 51%, when phosphorus was applied and alfalfa an increase of 168%. Spurway's test was VVL on the Hudson sample and L on the other two. Morgan's test was LM on the Hudson sample, MH on the others. Thus the response to added P was more or less in agreement with these tests. On the other

hand, the amount of readily soluble phosphorus as measured by the Runke method was quite high (240 p.p.m.—286 p.p.m. P_2O_5).

There was no response to potassium on any sample with any crop. Rapid soil tests gave low readings (medium by Spurway's method on one Ellis & Shaw sample) and the exchangeable potash was low (0.009%) on the Hudson sample and not any too high on the Ellis and Shaw samples. Some response to added potash might have been expected but none was obtained.

North Gower Clay

Soil samples were taken from the Kenny and Argue farms. The response (Table 12) of the cereals to nitrogen was again very good, from + 32% to + 50%, but again there was no response with the legumes (− 6% to + 8%). The total nitrogen content of the Kenny soil is fairly good (0.21%–0.24%) and that of the Argue soil is still better (0.30%–0.32%).

A good response to phosphorus was obtained in all cases except with oats on the Kenny sample where the average was only + 4%. The outstanding increase was 168% with alfalfa on the Argue soil. The Spurway method gave readings of L-VVL, the Morgan method all M, the Thornton gave M-H and the Guelph modification H-VH. The readily soluble P_2O_5 was very high, 245-409 p.p.m. Results by the Spurway method are the only ones that would indicate such a marked response to applied phosphorus.

No response to potassium can be claimed for this soil type. All averages were between the limits of − 4% and + 10%. All rapid soil tests registered low (except for one medium, on the Argue 1942-43 sample by the Spurway method) and the exchangeable potassium was also somewhat on the low side. A response to potassium was to be expected but was not obtained.

Rideau Clay

Soil samples were collected from the Rowe and Kennedy farms. The response (Table 13) of cereals to applications of nitrogen held true with this soil type also, the averages varying from + 19% to +64%. The legumes reacted to nitrogenous fertilization in a manner similar to that on the other soil types. The average increase with clover on the Rowe soil was 18%, but in the other three cases, decreases of from 3% to 16% were registered. Total soil nitrogen was 0.20% and 0.23% on the Rowe samples, and 0.33% and 0.34% on the Kennedy samples.

The response of cereals to phosphorus was + 15% or less in three cases, but was + 31% with barley on the Kennedy soil. The response of legumes was good (over + 30%) in three cases but only + 9% with clover on the Kennedy soil. Rapid soil tests by the Spurway method were VVL (1942-43 samples only), L-MH by the Morgan method, H by the Thornton method and VH by the Guelph modification. The Ruhnke method showed abundant amounts (323–388 p.p.m.) of readily soluble P_2O_5. Results by the Morgan method showed the best agreement with crop response, particularly in the case of the legumes.

With potassium, all crops showed a negative response (0 to − 18%) except clover on the Rowe soil which gave an average increase of 14%.

The Spurway test showed M-MH amounts present; the Morgan test indicated low K in the 1941-42 samples but very high amounts the next year; the Thornton test showed low amounts of potassium in the 1941-42 samples. Exchangeable potash was high in all cases. Except for the Morgan test the first year, the results showed satisfactory amounts of potassium present so that no response was to be expected.

DISCUSSION

In a broad survey of the foregoing results, probably the most outstanding fact is the difference shown by the cereals and the legumes in their response to the fertilizer nutrients. This is well shown by taking the average percentage increases in yield of cereals and in yield of legumes for each fertilizer element on each soil type and arranging them as in Table 14. The response of cereals to nitrogen has been general on all soil types studied, varying from an average increase of 28% on the Farmington loam to one of 198% on the Uplands sand. On the other hand, the lack of response of legumes to nitrogen has also been general. The greatest increase was only 12% on Rubicon sand, no other increase was above 4%, and a decrease was shown on the majority of the soil types, particularly on Kars gravelly loam (– 17%) and on Uplands sand (– 28%).

The response to applied phosphorus was quite good for both cereals and legumes. On only two soil types (Kars gravelly loam and Rubicon sand) was the increase on both crops less than 10%. In all other cases, an increase of more than 15% was obtained, the greatest being 63% with the cereals and 118% with the legumes on the Farmington loam. In general, the legumes showed a greater response to applied phosphorus than did the cereals.

The cereals showed little if any response to the application of potassium. An average increase of 19% was obtained on Rubicon sand but, except for Uplands sand (+ 9%) the averages on all other soils varied from + 5% to – 5%. The response of the legumes to potassium was noticeably better. On four types (Grenville loam, North Gower clay, Carp clay loam and Rideau clay), the average response was only 10% or less; on all others it was more than 20%. On the Rubicon sand, where the response of the cereals to potassium was greatest (19%), the response of the legumes to potassium was also greatest (78%).

In some cases, the results in Table 14 indicate quite clearly the treatments most required by a particular soil type. For example, on the Rubicon sand, the response to nitrogen and potassium was quite good, but practically no response was obtained when phosphorus was used. The Rideau clay gave no increased growth of crops due to potassium, but some with phosphorus on both kinds of crops, and with nitrogen on the cereals. Crops grown on the Farmington loam showed the greatest increase from phosphorus; legumes on this type gave the second greatest increase from potassium; cereals, on the other hand, gave the least response to nitrogen on this soil type.

Although no rapid soil test for nitrogen was made in this study, it is perhaps of some interest to observe the relationship between total soil nitrogen and the response obtained when nitrogen was applied to the soil. In two cases, the average percentage increase due to N was over 100%, and here the total soil nitrogen was not greater than 0.10%. The next

three soils, listed in decreasing order of their average response, had nitrogen contents varying from 0.15% to 0.18%. In the remaining soils, the amount of nitrogen present ranged between 0.25% and 0.36%; on these, the cereals gave the lowest, though still considerable, increases (28% to 45%).

Rapid soil tests for phosphorus were made by four methods (Spurway, Morgan, Thornton and Guelph) in one year and by two of these (Spurway and Morgan) in the second year. The individual results, together with the response of the crops of applications of P, are given in Table 15. One point that seems to be of importance is the tendency of these tests to give readings within certain ranges regardless of the soil type being tested, although the actual yields, as shown in Table 2, indicate a marked difference in fertility levels. Out of 35 individual samples examined by Spurway's method, 32 gave readings of L, VL or VVL. The other 3, on samples of Osgoode loam, were recorded as medium. There were no high readings. Forty-one samples were tested according to Morgan's method and, of these, 31 were recorded as M or MH. There were only two high readings. By Thornton's method, 16 out of 19 were M or H, 2 were VH and 1 L. When using the Guelph modification, 16 out of 19 were either H or VH, the other 3 being M and none was L. Thus there appeared to be a tendency for readings to be low by the Spurway method, medium to high by the Morgan and Thornton methods, and high to very high by the Guelph modification of the Thornton method. No particular correlation could be seen between the results by the rapid tests and the response to fertilizer treatments as measured by the greenhouse yields.

Rapid soil tests for potassium were made by three methods (Spurway, Morgan and Thornton) in the first year and by two of these (Spurway and Morgan) in the second year. The individual results, together with the response of the crops to applications of K, are given in Table 16. The tendency of all the methods is to give low readings. Out of 41 tests by the Spurway method, 34 were L or VL, with 5 reading M and 2 MH. By the Morgan method, 25 readings out of 29 were L or VL, with 2 giving M and 2 VH, while all 29 readings by the Thornton method were L or VL. By the Spurway method, 4 of the M and both MH readings were obtained on soils where no crop response to added potassium was obtained. To this extent, the rapid tests correlated with response to potash fertilization. The 2 VH readings by the Morgan method were on samples of Rideau clay which gave no response when potassium was added, but the other 2 Rideau clay samples gave low readings by this method. On this soil type, the response did not always correlate with the test.

SUMMARY AND CONCLUSIONS

Rapid soil tests for phosphorus and potassium have been made on 41 soil samples representing 11 of the main soil types of Carleton county. The methods used were those of Spurway, Morgan and Thornton, together with the Guelph modification of Thornton's procedure. The results of the tests were compared with the response obtained to fertilization by measuring the yields of crops (both cereals and legumes) grown in the greenhouse.

The different kinds of crops responded differently to the fertilizers used. In general, the cereals responded to nitrogen fertilization but the legumes did not; in one or two cases, a considerable decrease in the growth

of the legumes resulted from applying nitrogen to the soil. Both kinds of crops responded to phosphatic fertilization on all but the two soil types, with the legumes showing a greater response than the cereals. When potassium was applied to the soil, the cereals, except in one case, showed no response but, in 7 of the soils, a considerable increase in the yield of the legumes resulted.

Each of the rapid soil tests had a general tendency to give readings within a certain range regardless of the soil type. The Spurway method tended to give low readings for phosphorus; the Morgan and Thornton methods gave a very large proportion of medium to high readings; most of the readings by the Guelph modification were high or very high. When tests were made for potassium, readings by all three methods tended to be low.

The correlation between soil tests and crop yields was rather disappointing. Some of the difficulties in the way of interpretation have just been pointed out, i.e., the different response of cereals and legumes to the fertilizer elements applied, and the tendency for the methods to give values within certain ranges regardless of soil type. The application of rapid tests in the past has proved most useful when dealing with a single crop grown on closely related soil types and where a background of information regarding fertilizer response was available. This may continue to be the case for some considerable time. Any attempt to apply these methods on a variety of soil types, used for the growth of different crops, will be limited by the difficulties encountered in this investigation and perhaps by other difficulties as well. Their more general application will necessitate a rather careful calibration for each crop and for each soil type.

TABLE 1.—AREAS OF ELEVEN SOIL GROUPS OF CARLETON COUNTY

Soil types	Area (acres)	Per cent of total
Farmington loams, sandy loams, etc.	136,320	22.4
North Gower clay loam	76,160	12.5
Rideau clays	50,880	8.4
Grenville loams	43,520	7.3
Rubicon sand	35,200	5.8
Carp clay loam	22,720	3.8
Kars gravelly loam	22,200	3.7
Osgoode loam	21,440	3.5
Castor fine sandy loam	15,360	2.5
Uplands sand	13,120	2.2
Manotick sandy loam	9,280	1.5
	446,200	73.6

TABLE 2.—AVERAGE YIELDS* ON VARIOUS SOIL TYPES

Soil types	Barley grain	Clover dry yield	Oats grain	Alfalfa dry yield
Uplands sand	1.25	5.42	5.21	8.41
Rubicon sand	4.90	8.71	6.89	2.88
Kars gravelly loam	2.81	9.62	5.88	15.08
Manotick sandy loam	5.50	8.74	7.36	8.78
Castor fine sandy loam	4.35	8.02	8.37	8.58
Farmington loam	5.95	9.70	6.87	5.57
Grenville loam	7.98	6.95	9.26	11.48
Osgoode loam	8.46	13.23	12.08	11.30
Carp clay loam	8.02	12.61	8.97	9.95
North Gower clay	7.60	13.10	11.21	10.88
Rideau clay	12.33	15.66	11.30	18.54

* Grams per pot.

TABLE 3.—CROP RESPONSE IN GREENHOUSE AND RESULTS OF SOIL TESTS—UPLANDS SAND

Crop	Stewart										Lecuyer									
	% Increase due to N					% Soil N					% Increase due to N					% Soil N				
	alone	with P	with K	with PK	Avg.						alone	with P	with K	with PK	Avg.					
1941-42																				
Barley	+189	+482	—	+451	+374						—	—	—	—	—					
Clover	+ 8	− 20	—	− 15	− 9	0.03					—	—	—	—	—					
1942-43																				
Oats	+178	+138	+160	+109	+146						+76	+70	+97	+58	+75					
Alfalfa	− 37	− 56	− 22	− 64	− 45	0.08					−55	−42	−43	+26	−29	0.09				
	% Increase due to P					Rapid Soil Tests*					% Increase due to P					Rapid soil tests*				
	alone	with N	with K	with NK	Avg.	Sp.	Mo.	Th.	Gu.	Ru.	alone	with N	with K	with NK	Avg.	Sp.	Mo.	Th.	Gu.	Ru.
1941-42																				
Barley	−22	+56	−12	—	+ 7	L	MH	VH	H	53	—	—	—	—	—	—	—	—	—	—
Clover	+47	+ 8	+30	—	+28	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
1942-43																				
Oats	+22	+ 5	+27	+ 2	+14	VVL	L	—	—	80	+ 6	+ 2	+71	+41	+30	VL	M	—	—	100
Alfalfa	+42	−13	+66	−23	+18	—	—	—	—	—	+21	+56	−49	+13	+10	—	—	—	—	—
	% Increase due to K					Rapid soil tests*					% Increase due to K					Rapid soil tests*				
	alone	with N	with P	with NP	Avg.	Sp.	Mo.	Th.	% Ex.		alone	with N	with P	with NP	Avg.	Sp.	Mo.	Th.	% Ex.	
1941-42																				
Barley	+ 2	—	+16	+ 9	+ 9	L	VL	VL	Trace		—	—	—	—	—	—	—	—	—	
Clover	+41	—	+26	+34	+34	—	—	—	—		—	—	—	—	—	—	—	—	—	
1942-43																				
Oats	+15	+ 7	+19	+ 4	+11	L	VL	—	0.002		− 2	+10	+14	+ 6	+ 7	L	VL	—	Trace	
Alfalfa	− 3	+18	+13	− 8	+ 5	—	—	—	—		+47	+84	−38	+33	+32	—	—	—	—	

* Sp = Spurway, Mo = Morgan, Th = Thornton, Gu = Guelph, Ru = Ruhnke, % Ex = % Exchangeable, VH = very high, H = high, M = medium, L = low, VL = very low

TABLE 4.—CROP RESPONSE IN GREENHOUSE AND RESULTS OF SOIL TESTS—RUBICON SAND

Crop	Saunders										Hawkins									
	% Increase due to N					% Soil N					% Increase due to N					% Soil N				
	alone	with P	with K	with PK	Avg.						alone	with P	with K	with PK	Avg.					
1941-42																				
Barley	+46	+67	—	+73	+62	0.10					+38	+67	—	+69	+58	0.13				
Clover	− 7	−23	—	+15	− 5						+ 5	+ 2	—	+ 3	+ 3					
1942-43																				
Oats	+28	+ 1	+23	+47	+25	0.21					+52	−16	+89	+68	+48	0.16				
Alfalfa	+ 1	+108	+22	−28	+26						+51	+42	+10	−16	+22					
	% Increase due to P					Rapid soil tests*					% Increase due to P					Rapid soil tests*				
	alone	with N	with K	with NK	Avg.	Sp.	Mo.	Th.	Gu.	Ru.	alone	with N	with K	with NK	Avg.	Sp.	Mo.	Th.	Gu.	Ru.
1941-42																				
Barley	+ 5	+19	0	—	+ 8	L	MH	M	H	74	+16	+41	+14	—	+24	L	MH	L	H	39
Clover	+ 5	−13	−17	—	− 8	—	—	—	—	—	+19	+15	+19	—	+18	—	—	—	—	—
1942-43																				
Oats	+ 4	−17	− 7	+11	− 2	VL	M	—	—	66	+11	−38	− 2	−12	−10	L	M	—	—	128
Alfalfa	− 9	+86	+46	−13	+28	—	—	—	—	—	−15	−21	+23	− 5	− 4	—	—	—	—	—
	% Increase due to K					Rapid soil tests*					% Increase due to K					Rapid soil tests*				
	alone	with N	with P	with NP	Avg.	Sp.	Mo.	Th.	% Ex.		alone	with N	with P	with NP	Avg.	Sp.	Mo.	Th.	% Ex.	
1941-42																				
Barley	− 4	—	− 8	− 5	− 6	L	VL	VL	Trace		+14	—	+11	+13	+13	L	VL	VL	Trace	
Clover	+16	—	− 8	+38	+15	—	—	—	—		+47	—	+47	+49	+48	—	—	—	—	
1942-43																				
Oats	+11	+ 7	− 1	+44	+15	VL	M	—	0.012		+26	+58	+12	+124	+55	L	VL	—	0.009	
Alfalfa	+69	+104	+172	− 5	+85	—	—	—	—		+158	+88	+277	+125	+162	—	—	—	—	

*Sp = Spurway, Mo = Morgan, Th = Thornton, Gu = Guelph, Ru = Ruhnke, % Ex = % Exchangeable, VH = very high, H = high, M = medium, L = low, VL = very low

TABLE 5.—CROP RESPONSE IN GREENHOUSE AND RESULTS OF SOIL TESTS—KARS GRAVELLY LOAM

Crop	Redmond Bros.						McMenomy (1941-42), Lecuyer (1942-43)					
	% Increase due to N					% Soil N	% Increase due to N					% Soil N
	alone	with P	with K	with PK	Avg.		alone	with P	with K	with PK	Avg.	
1941–42												
Barley	+133	+208	—	+172	+171	0.08	+124	+198	—	+171	+164	0.07
Clover	− 5	− 7	—	− 9	− 7		+11	−17	—	−17	− 8	
1942 43												
Oats	+66	+76	+84	+92	+80	0.10	+120	+99	+101	+85	+101	0.15
Alfalfa	−17	−27	−28	−12	−21		−31	−42	−24	−33	−33	

Crop	Redmond Bros.										McMenomy (1941-42), Lecuyer (1942-43)									
	% Increase due to P					Rapid soil tests*					% Increase due to P					Rapid soil tests*				
	alone	with N	with K	with NK	Avg.	Sp.	Mo.	Th.	Gu.	Ru.	alone	with N	with K	with NK	Avg.	Sp.	Mo.	Th.	Gu.	Ru.
1941-42																				
Barley	− 1	+31	+ 4	—	+11	L	MH	VH	H	84	−20	+ 6	+ 9	—	− 2	L	M	H	H	46
Clover	+ 2	0	+21	—	+ 8	—	—	—	—	—	+26	− 5	+ 9	—	+10	—	—	—	—	—
1942-43																				
Oats	+ 2	+ 9	+ 7	+11	+ 7	L	M	—	—	113	+13	+ 2	+10	+ 1	+ 7	L	MH	—	—	283
Alfalfa	+ 9	− 4	− 4	+17	+ 5	—	—	—	—	—	+19	+ 1	+18	+ 4	+11	—	—	—	—	—

Crop	Redmond Bros.									McMenomy (1941-42), Lecuyer (1942-43)								
	% Increase due to K					Rapid soil tests*				% Increase due to K					Rapid soil tests*			
	alone	with N	with P	with NP	Avg.	Sp.	Mo.	Th.	% Ex.	alone	with N	with P	with NP	Avg.	Sp.	Mo.	Th.	% Ex.
1941-42																		
Barley	+ 2	—	+ 7	− 6	+ 1	L	VVL	VL	Trace	−20	—	+ 9	0	−4	L	VL	L	0.004
Clover	− 5	—	+12	+10	+ 6	—	—	—	—	+59	—	+37	+37	+44	—	—	—	—
1942-43																		
Oats	− 4	+ 6	0	+ 9	+ 3	L	VL	—	0.001	+ 1	− 8	− 1	− 8	− 4	L	L	—	0.002
Alfalfa	+32	+15	+17	+41	+26	—	—	—	—	+19	+31	+17	+36	+26	—	—	—	

* Sp = Spurway Gu = Guelph VH = very high L = low
Mo = Morgan Ru = Ruhnke H = high VL = very low
Th = Thornton % Ex = % Exchangeable M = medium

TABLE 6.—CROP RESPONSE IN GREENHOUSE AND RESULTS OF SOIL TESTS—MANOTICK SANDY LOAM

Crop	Lyttle										McClure (1941-42) and Goodwin (1942-43)									
	% Increase due to N					% Soil N					% Increase due to N					% Soil N				
	alone	with P	with K	with PK	Avg.						alone	with P	with K	with PK	Avg.					
1941-42																				
Barley	+33	+76	—	+91	+67	0.15					+16	+61	—	+39	+39	0.19				
Clover	− 5	+ 7	—	+14	+ 5						+ 6	+ 3	—	+ 1	+ 3					
1942-43																				
Oats	+32	+45	+48	+51	+44	0.15					+65	+44	+81	+85	+69	0.17				
Alfalfa	− 4	0	+21	+16	+ 8						+26	− 3	+ 1	−33	− 2					
	% Increase due to P					Rapid soil tests					% Increase due to P					Rapid soil tests*				
	alone	with N	with K	with NK	Avg.	Sp.	Mo.	Th.	Gu.	Ru.	alone	with N	with K	with NK	Avg.	Sp.	Mo.	Th.	Gu.	Ru.
1941-42																				
Barley	+ 7	+41	+ 1	—	+16	—	M	M−	M	39	− 1	+38	+ 9	—	+15	—	M	M−	M	61
Clover	+36	+54	+33	—	+41	—	—	—	—	—	+50	+45	+59	—	+51	—	—	—	—	—
1942-43																				
Oats	+13	+25	+44	+46	+32	L	M	—	—	222	+22	+ 7	+14	+17	+15	L	L	—	—	49
Alfalfa	+72	+79	+97	+90	+85	—	—	—	—	—	−12	−32	+57	+ 4	+ 4	—	—	—	—	—
	% Increase due to K					Rapid soil tests*					% Increase due to K					Rapid soil tests*				
	alone	with N	with P	with NP	Avg.	Sp.	Mo.	Th.	% Ex.		alone	with N	with P	with NP	Avg.	Sp.	Mo.	Th.	% Ex.	
1941-42																				
Barley	+10	—	+ 4	+13	+ 9	L	—	VL	0.002		− 3	—	+ 6	− 8	− 2	L	—	VL	0.006	
Clover	+17	—	+15	+21	+18	—	—	—	—		+ 4	—	+10	+ 9	+ 8	—	—	—	—	
1942-43																				
Oats	−19	− 9	+ 3	+ 7	− 5	L	L	—	0.013		− 3	+ 7	− 9	+17	+ 3	L	VL	—	0.004	
Alfalfa	−20	0	− 9	+ 6	− 6	—	—	—	—		+56	+24	+178	+91	+87	—	—	—	—	

* Sp = Spurway
Mo = Morgan
Th = Thornton
Gu = Guelph
Ru = Ruhnke
% Ex = % Exchangeable
VH = very high
H = high
M = medium
L = low
VL = very low

TABLE 7.—CROP RESPONSE IN GREENHOUSE AND RESULTS OF SOIL TESTS—CASTOR FINE SANDY LOAM

Crop	Waddell: % Increase due to N					Waddell: % Soil N	Quaile: % Increase due to N					Quaile: % Soil N
	alone	with P	with K	with PK	Avg.		alone	with P	with K	with PK	Avg.	
1941-42												
Barley	+ 4	+84	—	+84	+57	0.20	+68	+99	—	+118	+95	0.14
Clover	+10	– 2	—	−14	− 2		− 9	− 6	—	+ 4	− 4	
1942-43												
Oats	− 2	+12	− 1	+24	+11	0.21	+39	+53	+55	+41	+47	0.18
Alfalfa	+ 7	+ 5	0	− 1	+ 4		− 5	−19	−11	−17	−13	

Crop	Waddell: % Increase due to P					Waddell: Rapid soil tests*					Quaile: % Increase due to P					Quaile: Rapid soil tests*				
	alone	with N	with K	with NK	Avg.	Sp.	Mo.	Th.	Gu.	Ru.	alone	with N	with K	with NK	Avg.	Sp.	Mo.	Th.	Gu.	Ru.
	—				—	—	—	—	—	—	—				—	—	—	—	—	—
1941-42																				
Barley	+35	+140	+46	—	+74	L	MH	M	M	230	+ 2	+21	+ 8	—	+10	L	H	H	VH	280
Clover	+49	+34	+94	—	+59	—	—	—	—	—	+46	+51	+50	—	+49	—	—	—	—	—
1942-43																				
Oats	+140	+174	+122	+178	+154	VVL	L	—	—	213	+ 1	+11	+14	+ 3	+10	L	MH	—	—	345
Alfalfa	+256	+250	+226	+223	+239	—	—	—	—	—	+33	+14	+ 7	0	+18	—	—	—	—	—

Crop	Waddell: % Increase due to K					Waddell: Rapid soil tests*				Quaile: % Increase due to K					Quaile: Rapid soil tests*			
	alone	with N	with P	with NP	Avg.	Sp.	Mo.	Th.	% Ex.	alone	with N	with P	with NP	Avg.	Sp.	Mo.	Th.	% Ex.
1941-42																		
Barley	− 2	—	+ 5	+ 5	+ 3	L	—	L	0.004	−12	—	− 6	+ 3	− 5	L	—	VL	0.003
Clover	+16	—	+51	+31	+33	—	—	—	—	+35	—	+38	+53	+42	—	—	—	—
1942-43																		
Oats	+ 5	+ 7	− 3	+ 8	+ 4	L	VL	—	0.003	− 7	+ 4	+ 4	− 4	− 1	L	VL	—	0.009
Alfalfa	+37	+27	+25	+17	+27	—	—	—	—	+22	+14	− 2	0	+ 9	—	—	—	—

* Sp = Spurway
Mo = Morgan
Th = Thornton
Gu = Guelph
Ru = Ruhnke
% Ex = % Exchangeable
VH = very high
H = high
M = medium
L = low
VL = very low

TABLE 8.—CROP RESPONSE IN GREENHOUSE AND RESULTS OF SOIL TESTS—FARMINGTON LOAM

Crop	Featherstone										Fraser									
	% Increase due to N					% Soil N					% Increase due to N					% Soil N				
	alone	with P	with K	with PK	Avg.						alone	with P	with K	with PK	Avg.					
1941-42																				
Barley	+55	+72	—	+69	+65	0.20					− 2	+37	—	+17	+17	0.26				
Clover	+ 3	−10	—	−13	− 7						+13	− 2	—	−16	− 2					
1942-43																				
Oats	+16	+13	+ 3	+15	+12	0.34					+ 6	+33	0	+35	+19	0.31				
Alfalfa	−37	+ 8	−40	+ 2	−17						+ 7	−11	− 3	−15	− 6					
	% Increase due to P					Rapid soil tests*					% Increase due to P					Rapid soil tests*				
	alone	with N	with K	with NK	Avg.	Sp.	Mo.	Th.	Gu.	Ru.	alone	with N	with K	with NK	Avg.	Sp.	Sp.	Mo.	Gu.	Ru.
1941-42																				
Barley	−10	− 1	−11	—	− 7	L	MH	H	H	215	+51	+111	+70	—	+77	L	MH	M	H	268
Clover	+ 8	− 5	+26	—	+10	—	—	—	—	—	+35	+17	+57	—	+36	—	—	—	—	—
1942-43																				
Oats	+136	+130	+132	+160	+140	L	L	—	—	156	+33	+66	+17	+57	+43	L	L	—	—	140
Alfalfa	+177	+377	+235	+465	+314	—	—	—	—	—	+103	+69	+154	+122	+112	—	—	—	—	—
	% Increase due to K					Rapid soil tests*					% Increase due to K					Rapid soil tests*				
	alone	with N	with P	with NP	Avg.	Sp.	Mo.	Th.	% Ex.		alone	with N	with P	with NP	Avg.	Sp.	Mo.	Th.	% Ex.	
1941-42																				
Barley	+ 9	—	+ 9	+ 7	+ 8	L	—	VL	0.003		+ 4	—	+17	0	+ 7	L	—	VL	0.003	
Clover	+27	—	+48	+44	+40	—	—	—	—		+49	—	+74	+49	+57	—	—	—	—	
1942-43																				
Oats	+ 2	−10	0	+ 2	− 2	L	VL	—	0.005		+15	+ 9	+ 1	+ 2	+ 7	L	VL	—	0.004	
Alfalfa	+ 2	− 3	+23	+15	+ 9	—	—	—	—		+ 5	− 4	+31	+26	+15	—	—	—	—	

* Sp = Spurway, Mo = Morgan, Th = Thornton; Gu = Guelph, Ru = Ruhnke, % Ex = % Exchangeable; VH = very high, H = high, M = medium; L = low, VL = very low

TABLE 9.—CROP RESPONSE IN GREENHOUSE AND RESULTS OF SOIL TESTS—GRENVILLE LOAM

Crop	Dow										Stewart									
	% Increase due to N					% Soil N					% Increase due to N					% Soil N				
	alone	with P	with K	with PK	Avg.						alone	with P	with K	with PK	Avg.					
1941-42																				
Barley	+ 9	+38	—	+41	+29	0.29					—	—	—	—	—					
Clover	+ 9	+ 9	—	+ 4	+ 7						—	—	—	—	—					
1942-43																				
Oats	+ 1	+53	− 6	+29	+26	0.29					+41	+39	+36	+47	+41	0.25				
Alfalfa	+16	+ 9	+ 5	−16	+ 4						−31	− 9	−25	− 3	−17					
	% Increase due to P					Rapid soil tests*					% Increase due to P					Rapid soil tests*				
	alone	with N	with K	with NK	Avg.	Sp.	Mo.	Th.	Gu.	Ru.	alone	with N	with K	with NK	Avg.	Sp.	Mo.	Th.	Gu.	Ru.
1941-42																				
Barley	+26	+60	+11	—	+32	—	M	H	H	92	—	—	—	—	—	—	—	—	—	—
Clover	+89	+90	+48	—	+76	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
1942-43																				
Oats	+33	+103	+53	+110	+100	L	LM	—	—	77	− 1	− 2	−12	− 5	− 5	L	MH	—	—	121
Alfalfa	+102	+90	+151	+101	+111	—	—	—	—	—	+30	+72	+12	+44	+40	—	—	—	—	—
	% Increase due to K					Rapid soil tests*					% Increase due to K					Rapid soil tests*				
	alone	with N	with P	with NP	Avg.	Sp.	Mo.	Th.	% Ex.		alone	with N	with P	with NP	Avg.	Sp.	Mo.	Th.	% Ex.	
1941-42																				
Barley	+12	—	− 1	+ 1	+ 4	L	—	VL	0.004		—	—	—	—	—	—	—	—	—	
Clover	+46	—	+14	+ 8	+23	—	—	—			—	—	—	—	—	—	—	—	—	
1942-43																				
Oats	+ 8	0	+24	+ 4	+ 9	L	L	—	0.026		+ 4	+ 1	− 7	− 2	− 1	L	M	—	0.030	
Alfalfa	+ 3	− 7	+28	− 1	+ 6	—	—	—	—		+13	+23	− 3	+ 3	+ 9	—	—	—	—	

* Sp = Spurway Gu = Guelph VH = very high L = low
Mo = Morgan Ru = Ruhnke H = high VL = very low
Th = Thornton % Ex = % Exchangeable M = medium

TABLE 10.—CROP RESPONSE IN GREENHOUSE AND RESULTS OF SOIL TESTS—OSGOODE LOAM

Crop	Brown										Nixon									
	% Increase due to N					% Soil N					% Increase due to N					% Soil N				
	alone	with P	with K	with PK	Avg.						alone	with P	with K	with PK	Avg.					
1941-42																				
Barley	+34	+62	—	+79	+58	0.20					+33	+41	—	+33	+36	0.21				
Clover	−14	+15	—	− 2	0						+ 8	+23	—	− 4	+ 9					
1942-43																				
Oats	+35	+39	+26	+55	+39	0.15					+19	+22	+21	+15	+19	0.45				
Alfalfa	+ 6	+20	+ 3	− 1	+ 7						+ 5	− 9	− 6	−16	− 9					
	% Increase due to P					Rapid soil tests*					% Increase due to P					Rapid soil tests*				
	alone	with N	with K	with NK	Avg.	Sp.	Mo.	Th.	Gu.	Ru.	alone	with N	with K	with NK	Avg.	Sp.	Mo.	Th.	Gu.	Ru.
1941-42																				
Barley	+11	+34	−10	—	+12	M	H	M	H	322	+ 7	+13	+18	—	+13	M	MH	M	H	322
Clover	+22	+62	+70	—	+51	—	—	—	—	—	+11	+26	+15	—	+17	—	—	—	—	—
1942-43																				
Oats	+76	+81	+43	+76	+69	L	M	—	—	407	+ 8	+11	+ 8	+ 3	+ 8	M	M	—	—	511
Alfalfa	+46	+67	+115	+117	+86	—	—	—	—	—	+24	+ 7	+19	− 7	+14	—	—	—	—	—
	% Increase due to K					Rapid soil tests*					% Increase due to K					Rapid soil tests*				
	alone	with N	with P	with NP	Avg.	Sp.	Mo.	Th.	% Ex.		alone	with N	with P	with NP	Avg.	Sp.	Mo.	Th.	% Ex.	
1941-42																				
Barley	+ 4	—	−13	− 4	− 4	L	—	VL	0.005		− 7	—	+ 2	− 4	− 3	L	—	L	0.005	
Clover	− 5	—	+33	+ 8	+12	—	—	—	—		+14	—	+19	− 7	+ 9	—	—	—	—	
1942-43																				
Oats	+ 2	− 5	−17	− 8	− 7	L	VL	—	0.002		+ 1	+ 2	+ 1	− 5	0	M	L	—	0.004	
Alfalfa	+41	+38	+108	+71	+65	—	—	—	—		+20	+ 7	+15	+ 7	+12	—	—	—	—	

* Sp = Spurway; Mo = Morgan; Th = Thornton; Gu = Guelph; Ru = Ruhnke; % Ex = % Exchangeable; VH = very high; H = high; M = medium; L = low; VL = very low

TABLE 11.—CROP RESPONSE IN GREENHOUSE AND RESULTS OF SOIL TESTS—CARP CLAY LOAM

Crop	Ellis & Shaw										Hudson									
	% Increase due to N					% Soil N					% Increase due to N					% Soil N				
	alone	with P	with K	with PK	Avg.						alone	with P	with K	with PK	Avg.					
1941-42																				
Barley	+43	+59	—	+87	+63	0.45					—	—	—	—	—	—				
Clover	+10	− 2	—	+ 6	+ 5	—					—	—	—	—	—	—				
1942-43																				
Oats	+25	+37	+29	+38	+32	0.38					+27	+64	+ 7	+66	+41	0.26				
Alfalfa	−23	− 3	−10	+13	− 6						− 4	−22	− 5	−17	+12	—				
	% Increase due to P					Rapid soil tests*					% Increase due to P					Rapid soil tests*				
	alone	with N	with K	with NK	Avg.	Sp.	Mo.	Th.	Gu.	Ru.	alone	with N	with K	with NK	Avg.	Sp.	Mo.	Th.	Gu.	Ru.
1941-42																				
Barley	− 2	+ 9	− 9	—	− 1	L	MH	H	VH	245	—	—	—	—	—	—	—	—	—	—
Clover	+34	+20	+33	—	+29	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
1942-43																				
Oats	− 4	+ 6	+ 1	+ 8	+ 3	L	MH	—	—	240	+23	+60	+26	+96	+51	VVL	LM	—	—	286
Alfalfa	+60	+100	+75	+120	+90	—	—	—	—	—	+177	+126	+203	+166	+168	—	—	—	—	—
	% Increase due to K					Rapid soil tests*					% Increase due to K					Rapid soil tests*				
	alone	with N	with P	with NP	Avg.	Sp.	Mo.	Th.	% Ex.		alone	with N	with P	with NP	Avg.	Sp.	Mo.	Th.	% Ex.	
1941-42																				
Barley	+ 2	—	− 5	+12	+ 3	L	—	L	0.018		—	—	—	—	—	—	—	—	—	
Clover	− 8	—	− 9	− 1	− 6	—	—	—	—		—	—	—	—	—	—	—	—	—	
1942-43																				
Oats	− 6	− 3	− 1	− 1	− 3	M	L	L	0.013		− 3	−18	− 1	0	− 6	L	VL	—	0.009	
Alfalfa	− 7	+ 8	+ 1	+19	+ 5	—	—	—	—		+ 6	+ 4	+15	+22	+12	—	—	—	—	

* Sp = Spurway
Mo = Morgan
Th = Thornton
Gu = Guelph
Ru = Ruhnke
% Ex = % Exchangeable
VH = very high
H = high
M = medium
L = low
VL = very low

TABLE 12.—CROP RESPONSE IN GREENHOUSE AND RESULTS OF SOIL TESTS—NORTH GOWER CLAY

Crop	Argue										Kenny									
	% Increase due to N					% Soil N					% Increase due to N					% Soil N				
	alone	with P	with K	with PK	Avg.						alone	with P	with K	with PK	Avg.					
1941-42																				
Barley	+26	+63	—	+62	+50	0.32					+25	+61	—	+61	+49	0.24				
Clover	+17	− 1	—	− 9	+ 2						+16	+ 5	—	+ 3	+ 8					
1942-43																				
Oats	+34	+58	+20	+54	+42	0.30					+17	+32	+42	+37	+32	0.21				
Alfalfa	−11	−14	+ 5	− 2	− 6						− 8	−11	+ 4	− 7	− 6					
	% Increase due to P					Rapid soil tests*					% Increase due to P					Rapid soil tests*				
	alone	with N	with K	with NK	Avg.	Sp.	Mo.	Th.	Gu.	Ru.	alone	with N	with K	with NK	Avg.	Sp.	Mo.	Th.	Gu.	Ru.
1941-42																				
Barley	+ 5	+36	+11	—	+17	—	M	M	H	245	+24	+60	+10	—	+31	L	M	H	VH	409
Clover	+54	+31	+61	—	+49	—	—	—	—	—	+50	+36	+70	—	+52	—	—	—	—	—
1942-43																				
Oats	+34	+58	+26	+61	+45	VVL	M	—	—	311	+ 2	+15	0	− 3	+ 4	L	M	—	—	348
Alfalfa	+194	+186	+154	+136	+168	—	—	—	—	—	+34	+31	+55	+39	+40	—	—	—	—	—
	% Increase due to K					Rapid soil tests*					% Increase due to K					Rapid stoil tests*				
	alone	with N	with P	with NP	Avg.	Sp.	Mo.	Th.	% Ex.		alone	with N	with P	with NP	Avg.	Sp.	Mo.	Th.	% Ex.	
1941-42																				
Barley	− 2	—	+ 3	+ 3	+ 1	L	—	VL	0.012		+11	—	− 2	− 1	+ 3	L	—	VL	0.012	
Clover	+10	—	+14	+ 4	+ 9	—	—	—	—		− 4	—	+ 9	+ 7	+ 4	—	—	—	—	
1942-43																				
Oats	+ 2	− 8	− 4	− 6	− 4	M	L	—	0.014		− 9	+11	−11	− 7	− 4	L	L	—	0.010	
Alfalfa	+ 2	+20	−12	0	+ 3	—	—	—	—		− 2	+11	+13	+18	+10	—	—	—	—	

* Sp = Spurway, Mo = Morgan, Th = Thornton; Gu = Guelph, Ru = Ruhnke, % Ex = % Exchangeable; VH = very high, H = high, M = medium; L = low, VL = very low

TABLE 13.—CROP RESPONSE IN GREENHOUSE AND RESULTS OF SOIL TESTS—RIDEAU CLAY

Crop	Rowe										Kennedy									
	% Increase due to N					% Soil N					% Increase due to N					% Soil N				
	alone	with P	with K	with PK	Avg.						alone	with P	with K	with PK	Avg.					
1941-42																				
Barley	+53	+62	—	+77	+64	0.23					−15	+42	—	+30	+19	0.33				
Clover	+20	+ 4	—	+19	+14	—					−21	+ 6	—	+ 5	− 3	—				
1942-43																				
Oats	+47	+43	+46	+67	+51	0.20					+43	+48	+35	+54	+45	0.34				
Alfalfa	−12	−22	−19	−11	−16						−14	− 6	− 3	−23	−12	—				
	% Increase due to P					Rapid soil tests*					% Increase due to P					Rapid soil tests*				
	alone	with N	with K	with NK	Avg.	Sp.	Mo.	Th.	Gu.	Ru.	alone	with N	with K	with NK	Avg.	Sp.	Mo.	Th.	Gu.	Ru
1941-42																				
Barley	+20	+27	− 3	—	+15	—	MH	H	VH	388	− 4	+61	+37	—	+31	—	MH	H	VH	334
Clover	+62	+41	+25	—	+43	—	—	—	—	—	− 3	+30	− 1	—	+ 9	—	—	—	—	—
1942-43																				
Oats	+20	+17	+ 3	+18	+15	VVL	L	—	—	364	0	+ 3	− 1	+12	+ 4	VVL	M	—	—	323
Alfalfa	+31	+16	+34	+48	+32	—	—	—	—	—	+31	+44	+50	+20	+36	—	—	—	—	—
	% Increase due to K					Rapid soil tests*					% Increase due to K					Rapid soil tests*				
	alone	with N	with P	with NP	Avg.	Sp.	Mo.	Th.	% Ex.		alone	with N	with P	with NP	Avg.	Sp.	Mo.	Th.	% Ex.	
1941-42																				
Barley	+12	—	−10	− 1	0	M	L	L	0.032		−34	—	− 6	−14	−18	M	L	L	0.026	
Clover	+29	—	− 1	+13	+14	—	—	—	—		−10	—	− 9	−10	−10	—	—	—	—	
1942-43																				
Oats	+ 3	+ 2	−12	+ 3	− 1	MH	VH	—	0.045		0	− 6	− 2	+ 2	− 2	MH	VH	—	0.037	
Alfalfa	−11	−18	− 9	+ 4	− 9	—	—	—	—		− 6	+ 6	+ 8	−11	− 1	—	—	—	—	

* Sp = Spurway, Mo = Morgan, Th = Thornton, Gu = Guelph, Ru = Ruhnke, % Ex = % Exchangeable, VH = very high, H = high, M = medium, L = low, VL = very low

TABLE 14.—AVERAGE PERCENTAGE INCREASE OF CEREALS AND LEGUMES DUE TO APPLICATION OF N, P AND K

Nitrogen				Phosphorus				Potassium			
Cereals		Legumes		Cereals		Legumes		Cereals		Legumes	
Uplands	198	Rubicon	12	Farmington	63	Farmington	118	Rubicon	19	Rubicon	78
Kars	129	Carp	4	Castor	62	Carp	96	Uplands	9	Farmington	30
Manotick	55	Manotick	4	Grenville	42	Castor	91	Farmington	5	Castor	28
Castor	53	Osgoode	2	Osgoode	26	North Gower	77	Grenville	4	Manotick	26
Rubicon	48	North Gower	−1	North Gower	24	Grenville	57	Manotick	1	Kars	25
Carp	45	Grenville	−2	Manotick	20	Manotick	45	Castor	0	Osgoode	25
Rideau	45	Castor	−4	Carp	18	Osgoode	42	Kars	−1	Uplands	24
North Gower	43	Rideau	−4	Uplands	17	Rideau	30	North Gower	−1	Grenville	10
Osgoode	38	Farmington	−8	Rideau	16	Uplands	19	Carp	−2	North Gower	7
Grenville	32	Kars	−17	Kars	6	Kars	9	Osgoode	−4	Carp	4
Farmington	28	Uplands	−28	Rubicon	5	Rubicon	8	Rideau	−5	Rideau	−2

TABLE 15.—INDIVIDUAL RESULTS OF RAPID SOIL TESTS FOR PHOSPHORUS AND RESPONSE TO PHOSPHATIC FERTILIZERS

Soil types	Average response		Spurway	Morgan	Thornton	Guelph
	Cereals	Legumes				
	%	%				
Farmington	63	118	L L L L	MH MH L L	H M	H H
Castor	62	91	L L VVL L	MH H L MH	M H	M VH
Grenville	42	57	L L	M LM MH	H	H
Osgoode	26	42	M M L M	H MH M M	M M	H H
North Gower	24	77	L VVL L	M M M M	M H	H VH
Manotick	20	45	L L	M M M L	M– M–	M M
Carp	18	96	L L VVL	MH MH LM	H	VH
Uplands	17	19	L VVL VL	MH L M	VH	H
Rideau	16	30	VVL VVL	MH MH L M	H H	VH VH
Kars	6	9	L L L L	MH M M MH	VH H	H H
Rubicon	5	8	L L VL L	MH MH M M	M L	H H

TABLE 16.—INDIVIDUAL RESULTS OF RAPID SOIL TESTS FOR POSTASSIUM AND RESPONSE TO POTASH FERTILIZER

Soil type	Average response		Spurway	Morgan	Thornton
	Cereals	Legumes			
	%	%			
Rubicon	19	78	L L VL L	VL VL M VL	VL VL
Uplands	9	24	L L L	VL VL VL	VL
Farmington	5	30	L L L L	VL VL	VL VL
Grenville	4	10	L L L	L M	VL
Manotick	1	26	L L L L	L VL	VL VL
Castor	0	28	L L L L	VL VL	L– VL
Kars	−1	25	L L L L	VVL VL VL L	VL L
North Gower	−1	7	L L M L	L L	VL VL
Carp	−2	4	L M L	L VL	L
Osgoode	−4	25	L L L M	VL L	VL L
Rideau	−5	−2	M M MH MH	L L MH MH	L L

A DECIMAL SYSTEM FOR THE CLASSIFICATION AND MAPPING OF ONTARIO SOILS[1]

G. A. HILLS[2]

The most satisfactory system of soil classification is one in which provision is made for the many properties which characterize the soil profile[3]. In view of the large number of properties possessed by each soil body, and the way in which these vary from one soil to another, it would seem that such a classification would be practically impossible. However, it has been found that most properties can be arbitrarily placed in one of a few groups, each group reflecting some soil-forming factor or factors. Since most of the separations in the field must be based on physical properties, largely those which can be detected by the eye, the basis of field classification is largely outlined in terms of such properties. Associated with these are many other properties which can be determined only in the laboratory by chemical, physical and biological analyses. It cannot be too strongly emphasized that such groupings cannot be made on other than a philosophical basis. For example, in no other way is it possible to separate all the features of a soil profile which reflect the influence of geologic material from those features which indicate the effect of climate, vegetation and ground water.

In order to classify soils and map their distribution, there are required two schemes of classification, namely, the taxonomic and the chorologic. Taxonomic soil classification is concerned with breaking the soil into units which will fit into a logical scientific scheme. Such a scheme does not, by itself, serve for mapping purposes because soils are not distributed according to any taxonomic sequence. When a taxonomic scheme has been established on a theoretical but logical basis, certain "type" units can then be chosen as measuring sticks. The chorologic or mapping system is one of convenience for recording the distribution pattern of taxonomic units through the use of the "type" profiles.

THE DECIMAL SYMBOL FOR TAXONOMIC UNITS[4]

In order to provide as simple a scheme as possible for the orderly examination of soil profiles, the soil characteristics have been separated arbitrarily into four groups. The variations within each group are indicated by a symbol, either a figure or a letter. The symbols of the four groups together form a decimal symbol, each group occupying a definite position as indicated in Table 1.

---

[1] Presented before a meeting of the Soils Group of the Canadian Society of Technical Agriculturists, Toronto, Ontario, June 27–29, 1944.

[2] Formerly Dominion Soil Surveyor in Ontario, now with the Provincial Department of Lands and Forests, Toronto, Ont.

[3] The soil profile consists of a series of horizontal layers or horizons formed near the surface of the earth through the action of climate and living organisms upon the geological parent material. The individuality of soils can be noted by examining differences which occur along a vertical line drawn from points on the earth's surface toward its interior. A classification, based on soil profile, has been considered a genetic system since it shows differences and similarities of features which reflect the factors of soil formation. It must be remembered, however, that it is the characteristics of the profile, and not the factors of soil formation, which are classified. For the purpose of this paper, it was felt that an extensive bibliography was unnecessary. To those unfamiliar with this concept of soils, Dr. Kellogg's book, *The Soils that Support Us*, will prove most useful.

[4] Other decimal schemes of soil classification in use in America have been found useful in giving direction to, or in making comparisons with, the one outlined in this paper (1, 2, 9).

TABLE 1.—KEY TO DIGITS IN THE DECIMAL SYMBOL

0 0 0 0

Thousands Digit

Characteristics reflecting the regional climate and associated vegetation

Hundreds Digit

Characteristics reflecting the "fabric" of the geological parent material

Tens Digit

Characteristics reflecting the petrographic nature of the geological parent material

Units Digit

Characteristics reflecting the local environment factors, other than geological material

Each group of characteristics is subdivided on an arbitrary basis into major divisions. In order that these subdivisions be represented by numerals in the symbol, it is convenient to have not more than ten. Where it is necessary to have more, letters and other devices may be used. Since any subdivision of one group may combine with any one of the subdivisions of the other groups, a large number of combinations is theoretically possible. This number is further increased when combinations of types or transitions are recognized. Fortunately, however, only a few of the many possible combinations occur over a significant area in any one region.

The arrangement of the groups within the compound symbol is one of convenience for field classification. If the regional soil types (indicated by the thousands digit) have not been established previously, the soil surveyor decides these tentatively upon a precursory examination of the soil profiles on the well-drained locations, aided by a knowledge of the natural vegetation. As will be shown later, the final decision regarding soil regions can be made only after the local variations have been studied in detail[5]. Frequently all the soils within a mapping area belong to the same regional type so that this digit may be conveniently omitted on the map. An experienced surveyor will gain much information concerning the geological structure or fabric of the parent materials (hundreds column) by noting the topographical form of the landscape. For instance, he knows that the materials dominant in the ridges and basins of a terminal moraine are coarse, open, and stony, while those of a former lake-bed are more compact and stonefree. Information verifying these observations is obtained by examining the soil profiles in road-cuts and pits. Inspection of the rock fragments occurring in these profiles also aids him in determining the petrographical type of the parent material (the tens column). He next examines the range of local profile variations on each type of parent material which he records in the units column. These local variations must be

[5] Because a knowledge of local variations is basic to the discussion of regional types, these are discussed in this order and not as they occur in the mapping symbol.

properly correlated with all other variations within the same climatic region and the relationship established between them and local variations in adjoining regions.

THE STRUCTURAL TYPE OR FABRIC OF THE GEOLOGICAL PARENT MATERIALS[6]

The figures in the hundreds column of the decimal symbol indicate those features of the soil profile which reflect the structural type or fabric of the parent geologic material. They apply not only to the slightly weathered or unweathered materials immediately underlying the solum but also, as far as can be ascertained, to the original parent materials from which the solum has weathered, and as the latter may differ from the underlying, slightly weathered material, these are often difficult to determine. However, efforts are made to do this as fully as possible. The structural type or fabric refers to the nature of the physical elements of the soil skeleton and the proportion and arrangement of their individual particles within the geologic matrix. This includes the texture of the materials composing the fine skeleton, the type of sorting, compaction of materials, etc., all of which reflect the mode of deposition.

Table 2 outlines the main divisions.

TABLE 2.—KEY TO THE GEOLOGIC FABRIC (STRUCTURE) OF PARENT SOIL

0. Thin drift.
1. Coarse-textured open till.
2. Loamy till.
3. Heavy till.
4. Roughly stratified gravelly drift.
5. Uniformly stratified gravelly drift.
6. Heavy deep-water deposits.
7. Loamy deep-water deposits.
8. Roughly stratified sandy drift.
9. Uniformly stratified sandy drift.

a. Alluvial drift.
l. Loess deposits.
m. Muck deposits.
p. Peat deposits.
r. Residual drift.
etc.

Thin Drift (0 in the hundreds column)

This is the type found on deposits of varying texture which form but a shallow covering over bedrock. In a few instances they have weathered directly from the underlying bedrock (residual), but generally they have been deposited by ice, wind, or water. They are frequently stony regardless of the mode of deposition.

Coarse-Textured Till (1 in the hundreds column)

These are unassorted stony materials. The finer materials are usually a sandy loam in texture but loams are included where these are found in an open stony soil. This type is commonly associated with terminal and recessional moraines.

[6] For unfamiliar geological terms the reader is referred to texts on surface geology (7).

Loamy Till (2 in the hundreds column)

These are unassorted stony materials which are less open than the preceding type. Included in this type are light loams and sandy loams in which the stones are comparatively few and small in size. This also includes stonier soils in which the coarseness of the stony structure is modified by the compactness and heaviness of the materials between the stones. This type is commonly associated with ground moraines, frequently drumlinoid in nature. Some water-laid recessional moraines are also characterized by this type of material.

Heavy Till (3 in the hundreds column)

These are heavy soils in which fine grit and larger stones have but little effect on the porosity of the soil. The textural classes include clays, silty clays, and clay loams. In most cases they show little structure (unassorted), but there are occasional laminations due to ice pressure. This type of material is common in water-laid recessional moraines and in ground moraines. Much of the heavy till has originated from lake-laid deposits eroded by a readvance of the ice.

Roughly Stratified Gravelly Drift (4 in the hundreds column)

These are roughly-sorted gravels and coarse sands. The gravels are poorly rounded and, on the whole, are much more stony than in the deltaic deposits described below. Ice-rafted stones are common. These materials are common in eskers, kames, kame moraines, and in some beach formations. There are eroded and slumped edges of gravel terraces and deltas included in these types.

Uniformly Stratified Gravelly Drift (5 in the hundreds column)

These are uniformly sorted gravels commonly associated with deltas and terraces, which are generally uniformly bedded. The gravels are usually well-rounded and angular stones are uncommon. Heavy materials, if present, are in strata rather than comprising part of an unassorted matrix as in glacio-fluvial gravels described in No. 4.

Heavy Deep-water Deposits (6 in the hundreds column)

These are uniformly sorted and laminated clays, silty clays, and clay loams, associated with glacial lakes, marine seas and bays. Many of the glacial lake deposits show evidence of varving[7]. Marine deposits and very heavy lake-laid clays appear massive wherever the layering is difficult to detect because of uniform texture and colour.

Loamy Deep-water Deposits (7 in the hundreds column)

These are uniformly sorted and laminated loams, silt loams and fine sandy loams associated with glacial lakes and marine seas and bays. Layering and varving are common but there are also many deposits which can be identified as lacustrine only because of their stone-free nature.

---

[7] A "varve" is the annual deposition in a glacial lake consisting of two clayey layers, one of which having a higher content of silt or fine sand.

Roughly Stratified Sandy Drift (8 in the hundreds column)

These are roughly-sorted sands, loamy sands and sandy loams commonly associated with esker, kames, interlobate moraines and dunes. Where necessary, this group may be subdivided on the basis of wind and water deposition.

Alluvial Drift (*a* in the hundreds column)

These are materials of variable texture, often with marked changes within short vertical and horizontal distances. They are frequently laminated with a fairly high percentage of organic matter between the layers. Contortions of the laminations occasionally occur. This type of material is commonly associated with recent stream deposits.

Muck Deposits (*m* in the hundreds column)

These are accumulations of organic remains (plants and animals) which have been decomposed to the extent that their original form is not recognizable. They have also beep mineralized to a large extent either by the infiltration of sand, silt or clay, or by the release of minerals contained in the organic matter previous to its decomposition.

Peat Deposits (*p* in the hundreds column)

These are accumulations of organic remains (plants and animals) which have not been decomposed to the extent that their original form cannot be recognized.

PETROGRAPHIC TYPES OF GEOLOGIC MATERIALS

The figures in the tens column of the decimal symbol indicate the types of geologic materials according to the chemical composition of the rocks from which they are derived. While in some materials, other groups of elements are also important in soil development, the ten major divisions have been made on the proportionate content of silica, carbonate and clayey material. To these groups the terms siliceous, calcareous and argillaceous have been given in much the same sense as applied by Merrill (6) to stratified rocks, but have been extended to include similar materials occurring in any proportion in unconsolidated drift.

A. *Calcareous Materials*

Calcareous materials are characterized, in the main, by the content of calcium and magnesium carbonate. Rocks with a high percentage of carbonate are the limestones, dolomites and marbles. Many of the eruptive rocks such as diabase, and basalt, etc., yield small percentages of basic material upon weathering. The function of limy materials in soil development through the precipitation of coilloidal sols has been widely discussed (4).

B. *Siliceous Materials*

These are silica-bearing materials which do not readily produce colloidal material upon weathering. The silicate-bearing rocks such as shale and slate are therefore placed in a separate group. Rocks rich in siliceous

materials are gneiss, granite, sandstones, etc. These materials take little active part in soil development under Ontario conditions as they neither readily produce colloids nor perform any function in their translocation and precipitation. They function passively in permitting freedom of movement within the weathered profile.

C. *Argillaceous Materials*

Included in this group are those materials which readily yield colloids under the weathering conditions prevailing in Ontario. They are mainly derived from shales and slates. These materials furnish the chief elements functioning in all soil forming processes.

As most of the geologic materials upon which the Ontario Soils are formed, are transported rather than residual, the parent soil materials are commonly of mixed origin. It has, therefore, been necessary to establish, arbitrarily, ten subdivisions which contain increasingly proportionate amounts of each of the three types of materials. The arrangement of these "focal points" of petrographical composition is diagrammatically indicated by the isosceles triangle method used in mechanical analysis of soils (See Figure 1 and Table 4). No quantitative determinations have been devised to determine the position of materials within the graph. Its use is confined, at present, to indicate trends observed by field inspection.

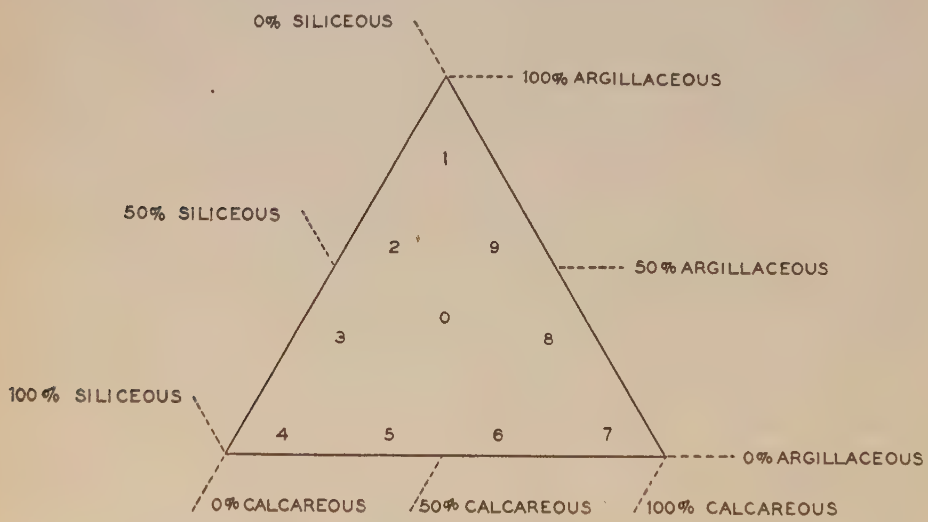


FIGURE 1. Diagram Showing Petrographical Type of Parent Material.

MAJOR PROFILE CLASSES

The units column of the decimal symbol is used to indicate local variations in soil profile, that is, those occurring within a climatic soil region. While such variations reflect all of the local environmental or soil-forming factors, major profile classes may be established which are based, in a large part, on characteristics which reflect the local climate and associated vegetation as conditioned by geologic materials and soil water. Within each major profile class there will be minor variations in the profile due to differences in the parent geologic materials, for which provision has been

made in the two preceding sections. The major profile classes are based on differences in the number, kind, and depth of the soil horizons within the profile. These horizons may differ in many ways, e.g., in structure, texture, colour, organic matter content, reaction, etc., such differences indicating not only kind, but also degree of development. A logical arrangement would appear to be a scale based on the degree to which soil development is controlled by local climate particularly soil moisture.

Within each climatic soil region there is a range of profile development with differences depending upon the degree to which climatic factors have been assisted or retarded by other soil forming factors. The maximum balanced development of an A–B profile is produced by that combination of soil-forming factors which permit the rainfall and temperature to exert their greatest combined influence. Under these conditions in Ontario, the development of the zone of eluviation[8] (A horizons) and the zone of illuviation[9] (B horizons) will be relatively proportionate or normal. Where the coincidence of soil forming factors permit the dominance of either temperature or moisture, a weak or disproportionate development takes place.

For convenience in classification, the generalized soil profiles common to a climatic soil region are diagrammatically arranged on a scale according to the type of development (see Figure 2). The juxtaposition is determined by the degree to which the moisture factor has been conditioned

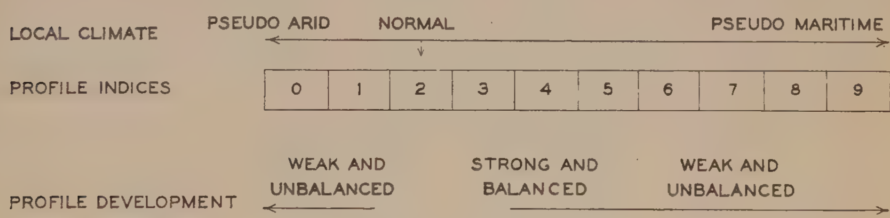


FIGURE 2. Major Profile Classes in Rotation to Climate.

by other soil forming processes. At the extreme left are the soils developed under a coincidence of soil forming factors in which the influence of soil moisture is at a minimum. This results in what Penck called a "pseudo-arid local climate". Ellis has termed this the "oromorphic site"(3). At the right are representatives of soils formed under the maximum influence of soil moisture within the region. Here exists what might be termed a pseudo-maritime climate, the hydromorphic condition as described by Ellis (3). The entire range has been divided into ten on an arbitrary and absolute basis and the divisions are indicated by indices 0–9.

The normal expression of both temperature and moisture for the region occurs at index 2, a condition defined by Ellis as "phytomorphic" (3). At this point the profile development is strong and balanced. Proceeding in either direction, the profiles become increasingly abnormal, either in point of weakness or unbalance. At the left (Index 0) there is little, if any, soil development and practically no soil moisture with the result that the

[8] Eluviation refers to the "outgoing" of iron, aluminum, etc. from the upper or A horizons.
[9] Illuviation refers to the incoming of iron, aluminum, etc. to the lower horizons (largely the B).

"soil" is little more than slightly weathered geologic materials and is therefore lithologic in nature. On the right (Index 9) the water factor becomes dominant to such an extent that the soils are practically hydrologic.

Classes Showing Lesser Influence of Soil Moisture

Soil profiles with indices occurring to the left of No. 2 in the profile scale reflect an increasingly lesser influence of soil moisture. Coincident with this is a greater variation in soil temperature. It is difficult to single out any one factor responsible for an abnormal profile development through a reduction in the effectiveness of rainfall. However, certain features may be mentioned which play an important part.

Steepness of Slope

This may cause a weak and/or truncated[10] profile in three ways.

(a) By merely reducing the amount of water percolating through the soil as a result of run-off and of greater evaporation due to exposure to wind. This results in a weak, but not necessarily an unbalanced, soil profile.

(b) By gradual removal, through normal erosion, of the leached materials while those in the leachate are permitted to accumulate in the B horizon. The results is a profile with all horizons present, but with the A more greatly reduced than the B.

(c) By the rapid removal through accelerated erosion of the upper portion of a profile already developed. Any or all the soil horizons may be affected.

Nature of Geologic Material

(a) Coarse open siliceous materials. These reduce the effectiveness of rainfall on account of the more variable soil temperature, more rapid percolation and scantier vegetation. These conditions result in a deep leached horizon, a B horizon either very thin or absent, and frequently a wide B_3 horizon.

(b) Materials with high carbonate content. These result in the formation of thin profiles. All the horizons are generally present though they are frequently very thin. In extreme cases, the only horizon which can be easily discerned is the surface, high in organic matter. Such soils are more droughty than the normal soils. (Profile Scales do not show this type of development.)

(c) Shallow materials over bedrock. Evaporation losses are high from shallow soil materials on account of low moisture holding capacity. The depth of soil profile may also be limited by the depth of unconsolidated material over the bedrock. The profile may be weak with all horizons present, or in some cases merely consist of a surface organic layer overlying a partially weathered parent material.

Time

On well-drained materials which have been exposed comparatively recently by erosion or deposition the profile may be abnormal (absent in extreme cases) due to the relatively short period of weathering.

[10] A weak profile is one in which all the horizons are developed to a small degree. A truncated profile is one in which the lower horizons exhibit a much stronger development than the upper, which may be entirely lacking.

Classes Showing Greater Influence of Soil Moisture

Soil profiles with indices occurring to the right of No. 2 in the profile scale reflect an increasingly greater influence of soil moisture. This increase in the influence of moisture is reflected in a number of ways. The layer of organic accumulation increases in depth and decreases in stage of decomposition. The eluviated horizon due to acid leaching becomes shallower and changes to a deeper horizon of alkaline leaching. The B horizon likewise undergoes a change. First there is a greater tendency for the formation of a pan condition in heavy materials and for iron concretions to become common in the lighter materials. In the heavier soils the B horizon is

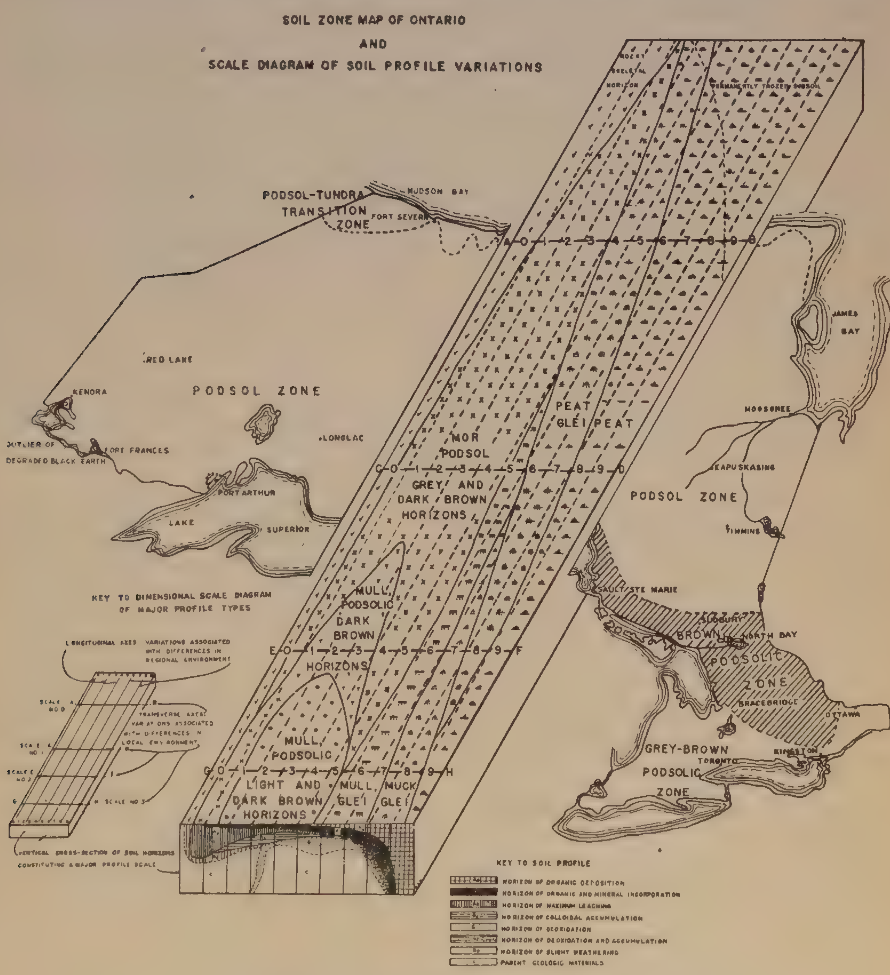


FIGURE 3. The scale diagram in Figure 3 is an attempt to show graphically the gradual slow changes throughout the province. On the longitudinal axes (with a north-south trend) are indicated the changes due to regional variations in climate, in Ontario is chiefly one of temperature. These regional changes give rise to soil zones. On the transverse axes are indicated soil changes due to local variations in climate. The east-west position of these axes have, therefore, no significance as to the east-west location of these local types. Cross sections along selected lines are shown in Figure 4.

gradually replaced by a horizon of accumulation in which much of the eluviated material remains in solution. Where the water table is more or less permanently high, a plastic subaqueous horizon, high in colloids, forms underneath the deep organic surface. A zone of alternate oxidation and reduction also becomes increasingly dominant until the position of a permanently high water table is reached. Rusty brown mottlings, which indicate alternate oxidation and reduction are found in both the horizons of eluviation and illuviation. The term glei has been applied to this zone of alternate oxidation and reduction and also to the greyish-blue, plastic, subaqueous horizon underlying the organic layer (see generalized diagrams, Figures 3 and 4). Factors which either singly or in combination tend to

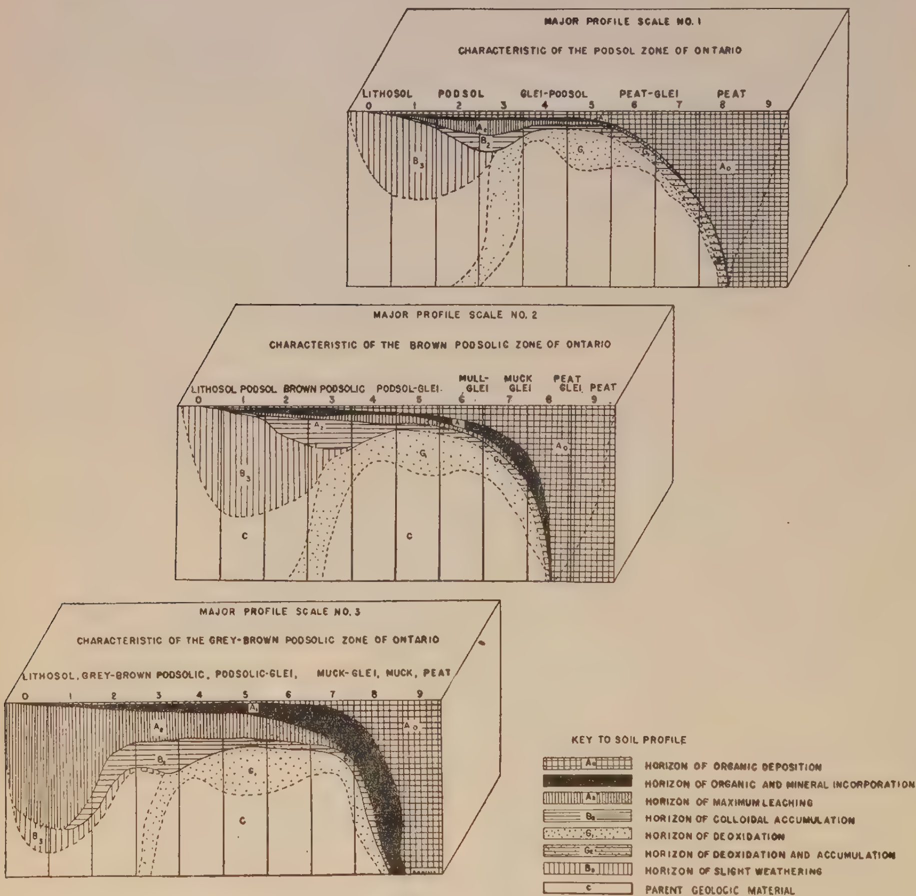


FIGURE 4. The Major Soil Profile Scales for Ontario.

increase the effectiveness of rainfall and render temperature less effective are: (1) heavy and compact soil materials, (2) smooth topography, (3) high regional water table, and (4) the initiation of a moor vegetation. True lithosols or hydrosols are barely within the pedologist's field and consequently are placed at the extremes of the scale and give little weight to the indices. Within the scale the change of characteristics from one

extreme to the other is gradual and varies considerably in detail in different soil materials. *While a separate scale diagram for each type of material within a climatic soil region may be considered desirable, a single combination scale has proven most useful providing its composite nature is recognized.*

Under the cool humid climate prevailing throughout Ontario, podsolization processes operate wherever drainage conditions permit. These are most active on the "normal" sites where the soil-forming factors permit the fullest expression of the climatic agencies. They become less active with the increased influence of those factors which tend to create the pseudo-arid or pseudo-maritime conditions. As drainage becomes poorer, podsolization is gradually replaced by gleization and increased organic accumulation. Figure 3 is a generalized diagram showing these types of profile development arranged according to the profile scale.

Discussion of Certain Profiles

Profile Index 0

The profile at index 0 may be described as an $A_0 - C_1$ type. This profile is developed under conditions which place the maximum restriction on the effectiveness of the rainfall.

The soil profile at this index is extremely shallow or may be entirely absent. The A_0 and A_1 horizons are very thin. The B horizon is also extremely shallow if present. The upper portions of the geologic materials are usually weathered slightly to form a C_1 horizon. Usually the site is excessively drained with the water table below 6 feet. The natural vegetation has modifications which adapt it for a dry environment, i.e. it is zerophytic.

Profile Index 1

The profile at index 1 may be described as an $A_{1\text{-}2}$ $(B_2)B_3$ type. The factors which limit the maximum balanced development are the same as those outlined for index 0 but here they are operating with a lower intensity.

The A_0 and A_1 horizons are comparatively shallow. The A_2 is abnormal but variable, being very deep in siliceous materials and quite shallow if calcareous and argillaceous. The B_2, if present, is very narrow. The B_3 horizon is usually quite thick in siliceous materials and very thin in those high in clay or lime.

Profile Index 2

The profile at index 2 may be described as an $A_{1,2,3}$ $B_{1,2,3}$,C. The environmental conditions are optimum for the maximum development of a well-balanced profile reflecting the regional climate and associated vegetation. The A and B horizons are well-developed and in proportion to each other. Both of these are well subdivided into subhorizons which reflect only those processes associated with the regional climate, which, in Ontario, are types of podsolization.

Soil drainage is good but not excessive. The water table is usually at depths greater than 6 feet. These features are usually conditioned by an undulating topography but are also found on smoother and more rolling sites depending on the texture of the soil material. Natural vegetation

may also play a dominant rôle in moisture control. The geologic materials are commonly of intermediate texture. Heavy soils with open structure and light soils with capacity to form moisture retaining horizons are also included. The petrographic nature of the parent material also affects optimum soil development. Very high content of either siliceous, argillaceous or calcareous materials will result in a development which is abnormal for the region particularly since the period of weathering in Ontario since glaciation has been so short. Conditions which are optimum for the maximum balanced soil development are likewise optimum for the development of the regional mesophytic vegetation, i.e., plants requiring normal moisture conditions. This is the climatic climax of the ecologist. (8).

Profile Index 3

The profile at index 3 is commonly marked by a slight under-development in both the A and B horizons and by the presence of slight mottlings. In the heavier soils the B horizon tends to be comparatively wide although there are indications that the material actually translocated is less densely accumulated at any particular point than is the case af the B at index 2. Factors which either singly or in combination tend to increase the effectiveness of rainfall and render temperature less effective are heavy and compact soil materials, gentle slopes and a higher regional water table.

Profile Index 4

At index 4 the effect of temperature is still further reduced by a coincidence of factors which retard soil drainage. Such factors have been outlined at Index 3 and include soil materials still heavier or more compact, a smoother topography, or a maintenance of the water table at a higher level than under the conditions prevailing at Index 3. The profile is commonly characterized by an induration of the B horizon. In the heavier soils there is a tendency to form the clay pan or otherwise cemented hardpan commonly associated with the planosols. (These hardpan conditions are not as highly developed in Ontario as in neighbouring areas of the United States which have been subjected to weathering for longer periods of time.) In the lighter soils, lenses of iron pan are found at this index. In nearly every case, there is a more pronounced mottling, indicating greater deoxidation.

Profile Indexes, 5, 6, 7, 8, 9

The development of these profiles is conditioned by a high water table which renders the leaching properties of soil water less effective. The result is a wider horizon of accumulation, a shallow grey leached horizon, and the maximum development of a deoxidized horizon (the glei). For variations see generalized diagram, Figure 4.

These are intrazonal hydromorphic soils which include the wiesenböden (of marshy meadows), the ground water podsols, and the half bog soils.

Profiles at indexes 8 and 9 indicate conditions where the influence of soil water is at its maximum and that of soil temperature is at its minimum. At index 8, the profile is that of a bog soil. The profiles of bog soils differ in detail with climate and adjacent upland areas. At index 9 are profiles transitional in nature between the bog soils and the true hydrosols.

FEATURES OF THE SOIL PROFILE REFLECTING REGIONAL CLIMATE

The features of the soil profile which reflect regional climate (found in the thousands column) are those associated with organic matter and soil weathering. Climate broadly determines the type of natural vegetation and accordingly the type of organic remains which is to be associated with the soil. Climate, too, is the factor which largely determines the extent to which organic matter will be incorporated into the soil and how much will remain on the surface. Climate determines the type of chemical weathering and the processes of translocation of the weathered products within the soil. The climatically controlled processes reflected in the soils of Ontario are organic accumulation, melanization, podsolization, and gleization.

Organic accumulation requires little definition. In cool, humid climates, the organic matter decomposes slowly and therefore accumulates on the surface in increasing amounts. A layer of slightly decomposed organic matter is termed the A_0 horizon. It is thin in places where the type of vegetation and the climate favours its decomposition and incorporation with the mineral soil. In this case, the decomposition may be proceeding rapidly to form a thick A_2 horizon. Where the process is slow, organic matter accumulates more rapidly and at greater depths. In profiles in which the organic matter of the A_0 tends to form an A_1 layer but slowly, the combined horizons are called *mor*, where the layer is shallow. Deeper layers of poorly decomposed organic matter are known as peat.

Melanization is the process of uniting organic and inorganic soil materials and results in the formation of a very dark horizon (the A_1). This is usually a mineral soil high in organic matter. It may also refer to a well decomposed and mineralized organic soil (muck). Melanization is associated with warm humid and subhumid climates. It is most highly developed under grass but may also be the dominant process under hardwoods. The process is promoted by a good calcium supply. In fact the northward extension of this process occurs mainly on sites on which the available calcium is high. Where the organic matter is being largely transformed from an A_0 to an A_1 condition, the combined organic horizons are often referred to as *mull*.

Podsolization is a leaching process which tends to remove iron and aluminum, etc., from the upper soil horizons and deposit them in a lower one. This leaching process occurs on the better drained soils of temperate forest regions, but becomes most intensive in the cooler and more humid regions of the coniferous forests with their unincorporated acid humus or mor. The downward-moving rain-water, percolating through the shallow layer of organic matter, becomes acid. These acidified waters remove varying amounts of iron, aluminum and other elements from the upper mineral layer depending on the type of organic matter through which it passes. The leaching results in an ashy grey horizon (A_2) low in iron and aluminum and rich in silica (sand). The degree of greyness in the leached horizon is usually indicative of the intensity of leaching. To these soils with an ash-like leached layer, the Russians have given the name "podsol". Underlying the leached A_2 horizon, the B, in which there is an accumulation of the iron, aluminum and clay colloids leached out of the A_2 above.

Gleization is the process involving the alternate oxidation and reduction of the products of weathering in a dispersed form. This process occurs under poor drainage conditions in all climatic regions. In warm regions it is associated with processes of humus incorporation. In the cooler, more humid climates, it is associated with the process of peat formation, in which there is organic accumulation with little melanization. Two phenomena result from the rise and fall of the water table. First there is the phenomenon of alternate oxidation and reduction. When the water table is low, the soil is aerated and oxidation takes place. When the soil is again saturated, the materials are reduced. The rusty, brown mottling which characterizes soils under these conditions indicate the presence of reduced iron oxides. This horizon is known as the glei (gley) or G_1. Secondly, when the water table is low, the soil above it is subject to weathering and the products of weathering are leached downward. These accumulate in a dispersed form in contrast to the accumulation of precipitated colloids in the B horizon resulting from podsolic leaching. When in close proximity to the water table this horizon is commonly deoxidized and grey to blue in colour. In clay soils it is extremely plastic when wet, and brittle when dry. This horizon too, has been called the glei (gley), frequently the G_2, to distinguish it from the G_1, although often they occur in such intimate association that there is not a distinct line of demarcation between them.

All of these processes occur throughout Ontario, but there is considerable variation in the degree to which each is operating. The results are modifications in the major profile scale. If all the modifications within the province are to be taken into account, innumerable variations of the generalized scale would be necessary. However, the range of modifications has been divided into four, and scales have been established to represent four main climatic soil zones. Outliers of two other zones also occur. The subdivisions of the thousands column are indicated in Table 3. Further detail concerning regional types are illustrated in Figures 3 and 4.

Table 3.—The key to digits in the thousands column

0. Tundra (Moor), Mean Line AB (Figures 3 and 4).
1. Podsol (Moor), Mean Line CD (Figures 3 and 4).
2. Brown Podsolic, Mean Line EF (Figures 3 and 4).
3. Grey Brown Podsolic, Mean Line GH (Figures 3 and 4).

CHOROLOGIC OR MAPPING UNITS

A chorologic or mapping scheme of classification is necessary since soils do not always occur in areas sufficiently uniform to use taxonomic units for mapping purposes. It has been conceived that a taxonomic type may embrace a reasonable range of characteristics. Upon this basis, Marbut established the soil type as a unit serving both taxonomic and chorologic purposes. The difficulties which have arisen through the failure to recognize the position of the soil type in the two classificatory systems are well-known to many soil surveyors. Kellog (5) points this out and stresses the need of the soil complex as a mapping unit of greater variability.

The chorologic or mapping unit, then, is a means of recording the distribution pattern of taxonomic units which the soil surveyor will encounter in the field. Certain taxonomic types must be considered as focal points from which to measure the degree of deviations. The soil surveyor first decides the taxonomic type and records it by means of the decimal symbol. If the characteristics in a mappable area are sufficiently uniform and do not extent beyond the range arbitrarily established for a taxonomic unit, it is evident that the area mapped will represent both a mapping and a taxonomic unit. When various decimal symbols appear on the field sheets in such a way that the separation of uniform areas of soil is impossible, a mapping unit covering a greater range of conditions is then established which may be more accurately called a soil complex. This unit embraces comparatively wide variations in type of geologic materials as well as change in the major profile class. If the unit mapped involves only profile variations upon similar parent material, the term catena (1) is used as indicated in Table 4. All soils in the same catena have the same tens and the hundreds column of the decimal symbol. The catena is similar to the soil association of Ellis (3). The terms series and types are common in the soil survey literature and should require no further discussion here.

TABLE 4.—SUMMARY TABLE SHOWING THE DECIMAL TAXONOMIC SUBDIVISIONS OF THE MAPPING SYMBOL

ZONAL TYPE	Catena		Series*	Type
Thousands digit	Geologic Fabric *Hundreds digit*	Petrographic Composition *Tens digit*	Profile Class *Units digit*	Textural Class *Tenths digit*
0. Tundra	0 Thin drift	0. Almost equal proportions of argillaceous, siliceous and calcareous.	0. A_0–C_1 profile	s —sand
1. Podsol	1. Coarse textured till	1. Almost entirely argillaceous	1. $A(B_2)B_3$ profile	ls —loamy sand
2. Brown podsolic	2. Loamy till	2. Mostly argillaceous, some siliceous.	2. $A_{1,2,3}$,$B_{1,2,3}$, C profile	sl —sandy loam
3. Grey-brown podsolic	3. Heavy till	3. Mostly siliceous, some calcareous	3. A–B (G) profile	fsl —fine sandy loam
	4. Roughly stratified gravelly drift	4. Almost entirely siliceous	4. ABG profile	l —loam
	5. Uniformly stratified gravelly drift	5. Mostly siliceous, some calcareous	5. A(B)G profile	si l —silt loam
	6. Heavy deep-water sediments	6. Mostly calcareous, some siliceous	6. (M)AG profile†	si c —silty clay loam
	7. Loamy deep-water sediments	7. Almost entirely calcareous	7. MG profile†	cl —clay loam
	8. Roughly stratified sandy drift	8. Mostly calcareous, some argillaceous.	8. PG profile‡	c —clay
	9. Uniformly stratified sandy drift	9. mostly argillaceous, some calcareous	9. P profile‡	h c —heavy clay
	a. alluvial drift			
	l. loess			
	m. muck			
	p. peat			
	r. residual			

* 1 for grey-brown podsolic zone.
† M (muck) melanized layer.
‡ 3 P for peat.

TABLE 5.—KEY TO MAJOR SOIL TYPES OF CARLETON COUNTY—A. Major Profile Types Common to the Grey Brown Podsolic Zone

SCALE→	0	1	2	3	4	5	6	7	8	9
CHARACTERISTIC PROFILE FEATURES→	Thin light brown surface horizon over slightly modified parent material, An A_1C_1 profile	Brown surface; weakly developed horizon of accumulation (the B). An $A_{1,2}(B_2)B_3$ profile (B_2) = faint development	Greybrown surface; the leached A_2 and the B are well developed. An $A_{1,2,3}$–B_2–B_3 profile	Grey brown surface; the leached A_2 and the B fairly well developed. Weak development of a mottled glei. An $A_{1,2,3}$–B_2–B_3–G profile	Thick grey brown surface greyish leached A_2 weakly developed B with mottled glei. An $A_{1,2}$–B–G profile	Thick dark grey surface greyish leached A_2 with mottling in lower part. An $A_{1,2}(B)$–G profile. (B) = faint development	Very thick dark grey mineral surface overlying mottled and/or sticky glei. An $A_{1,2}$–G profile	Dark grey muck overlying mottled and/or sticky glei. An A_1G profile	Brownish peat over dark mucky horizon, then mottled and/or sticky glei. An A_0–A_1–G profile	Brownish peat. An $A_0(A_1)G$ profile.
ASSOCIATED CHARACTERISTICS→	Shallow, steeply sloping, or coarse textured materials excessively drained	Rolling or light textured land with excessive to good natural drainage	Rolling to undulating lands with good natural drainage	Undulating land with natural drainage slightly restricted	Smooth land with moderate surface drainage and moderate to slow internal drainage	Smooth land with slow internal and external drainage	Almost level land with very slow internal and external drainage	Almost level swamp land. Intermittent external drainage, very slow internal drainage	Depressional bog areas. Water held by ponding or by organic accumulations	Depressional bog areas. Water held by ponding or by organic accumulations
THE CATENAS↓	The Soil Complexes, Types and Phases									
Compact loamy till comprised chiefly of sandy limestone materials	←– – Grenville loam – –→ ←Grenville sandy loam→ ←– – – – – – – – Grenville bouldery phase – – – –→					← Lyons loam →				
Heavy shaley till					Ellwood clay loam					
Water-laid grey clays and silts, low in lime					Rideau clay Rideau clay sand spot		North Gower clay loam			
				Rideau clay rock knob phase						
Water-laid clays and silts medium in lime					Carp clay loam			N. Gower–shallow muck ph.		
Water-laid pink and grey clays low in lime					Bearbrook clay Bearbrook clay sand spot phase					
Water-laid loams medium in lime						Osgoode loam				
Stratified sands medium high in lime							Granby s and s.l.			
Roughly stratified sands and gravels, medium to low in lime	Kars gravelly sandy loam									
Shallow drift (usually limy) over limestone bedrock	←Farmington undiffer.→ ←– – – Farmington loam – – – – – – –→ Farmington sandy loam→ Farmington shingly 1→ ←– – – – – – Farmington clay loam – – – – – – – – –→									
Shallow drift low in lime over sandstone bedrock	Nepean sand									
Shallow shaley drift low in lime over shale bedrock	Leitrim gravelly loam									
Deposits of neutral to alkaline organic matter (muck) overlain in places by acid slightly decomposed organic matter (peat)								←———Muck———→	Peat	

←– – – – – – – – – – – –→ indicates the profile range of at least 75% of the type as mapped.

TABLE 5.—KEY TO THE MAJOR SOIL TYPES OF CARLETON COUNTY—Continued—B. Major Profile Types Common to the Brown Podsolic Zone

SCALE→	0	1	2	3	4	5	6	7	8	9
CHARACTERISTIC PROFILE FEATURES→	Thin grey brown surface horizon over slightly modified parent material. An A_0–C_1 profile	Thin grey brown A_0 weakly developed light grey A_2 and brown B. An $A_{0,2}$ (B_2)–B_3 profile	Grey brown surface, thin leached A_2, brown B. An $A_{0,1,2}$ $B_{1,2,3}$ C profile	Grey brown surface thin leached A_2 brown B and mottled G. An $A_{0,1,2}$ $B_{2,3}$ G profile	Dark grey organic A_0 over light grey leached A_2 reddish brown B mottled glei. An $A_{0,2}$–B–G profile	Dark grey organic A_0 over light grey leached A_2 with mottling on lower part of profile the glei. An $A_{0,2,}$(B)G profile	Dark grey A_1 over greyish mottled A_2 and glei. An $A_{1,2,}$ G profile	Dark grey muck overlying mottled and/or sticky glei (G). An A_1–G profile	Brownish peat over dark mucky horizon then mottled or sticky glei. An $A_{0,1}$–G profile	Brownish peat. An A_0–G profile
ASSOCIATED CHARACTERISTICS→	Shallow steeply sloping or coarsely textured materials excessively drained	Rolling light textured land with excessive natural drainage	Rolling medium textured material not excessively drained under forest	Undulating land with natural drainage slightly restricted	Smooth land with moderate to slow natural drainage	Smooth land with slow natural drainage	Almost level land with very slow natural drainage	Almost level swampy land. Intermittent run-off, Internal drainage very slow	Depressional bog areas. Water held by ponding or by organic accumulations	Depressional bog areas. Water held by ponding or by organic accumulations
CATENAS↓	The Soil Complexes, Types and Phases									
Loamy siliceous till, medium low in lime		Galesburg sandy loam								
Water laid grey clays and silts low in lime				Renfrew clay						
					Renfrew comp. subsoil					
Waterlaid pink and grey clays overlain by sands, clays and sands, low in lime						Bearbrook clay sand spot phase				
Waterlaid fine sands and silts, low in lime					Castor silt loam					
Waterlaid sands over acid clays, low in lime		Manotick sandy loam				Allendale sandy loam				
Uniformly stratified sands and gravels, low in lime	Uplands sand				Rubicon sand					
Shallow drift medium to low in lime over basic Precambrian bedrock	Chandos sand									
Shallow acid drift over acidic Precambrian bedrock	Anstruther sand									
Wind blown sand	Bridgman sand									
	← Eastport sand →				← Eastport sand →					

←------ ------→ indicates the profile range of at least 75% of the type as mapped.

NOTES:

(1) THE DISTRIBUTION GRAPH in the upper part of each land type chart applies to the combination of the two groups of soil characteristics shown below it, namely; (a) The climatic soil profile types superimposed upon (b) The type of parent geological materials.

(2) MAJOR PROFILE SCALE NUMBERS for numbers 1 and 2 see figures 3 and 4, also discussions accompanying these scales. No. 1T refers to a transition from podsol to the degraded black earths.

(3) PROFILE CLASS NUMBERS 0 to 9 indicate variations within major scales. See figure 4 and discussions under major profile classes.

(4) KEY TO GEOLOGICAL MATERIALS

ORGANIC MATERIALS

HEAVY TEXTURED LIMY MATERIALS

INTERMEDIATE TEXTURED LIMY MATERIALS

COARSE GRAVELLY ACIDIC MATERIALS

GRIT

STONES

PRECAMBRIAN BEDROCK

FIGURE 5. Distribution Pattern of Taxonomic Units.

While the use of the soil complex as a mapping unit expressing greater variability than the soil type is a step in the right direction, it would hardly seem to go far enough. To establish a boundary between these at any arbitrary point would merely indicate that the soil type is comparatively homogeneous and the complex comparatively heterogeneous. It would seem advisable to establish some device to indicate the distribution pattern of the taxonomic units. This the author has attempted to do in the following keys for Carleton County (10) and Rainy River District (11). (See Table 6 and Figure 5.)

An examination of Table 6 indicates that few of the soil types have a range as uniform as that of the taxonomic units with which they were measured. Many types such as the Grenville loam could be fairly easily identified by a single symbol, others such as the Lyons loam and Rubicon sand occupy portions of a catena. Then there are those such as Farmington clay which might run the whole gamut of the catena. The North Gower, as mapped, is neither a soil type nor a soil catena, but a soil complex since it is found on more than one type of parent material. In the reconnaissance survey in Northern Ontario (11) no attempt has been made to approximate homogeneity of the soil type. More inclusive and less precise mapping units namely the land class and the land type were established using land form and vegetation as the mapping criteria. While this demanded another mapping scheme than that used in the Soil Survey of Southern Ontario, it was found that the average range of profile characteristics could be described by using the same major profile scales. An attempt has been made to indicate the average distribution by a curve, (see Figure 5).

This system of classification was first used in Ontario during the Carleton County Survey in 1940. Since then it has undergone considerable changes and will doubtless require further modifications or clarification before it is suitable for all of Ontario. In spite of this lack of perfection, the system is now serving a very useful purpose not only in the correlation of soils within local areas, such as counties, but also in broader ecological studies of relationship of soils to crops and natural vegetation. Granted that its use demands considerable experience and knowledge of soils for those who would use it, it is doubtful whether a system of classification could be devised which would render soil survey a matter of simple routine.

ACKNOWLEDGMENT

The author is indebted to all those who were associated with him on soil survey projects sponsored by the Dominion and Provincial Departments of Agriculture. He is particularly grateful for the assistance of Messrs. N. R. Richards and L. R. Webber who laboured with him in the field and to Messrs. L. J. Chapman, A. Leahey, F. F. Morwick, D. F. Putnam and P. C. Stobbe for their liberality in constructive criticism.

Mr. R. N. Johnston, Chief, Research Division, Department of Lands and Forests, has kindly facilitated the final preparation of both manuscript and charts.

REFERENCES

1. Bushnell, T. M. Some aspects of the catena concept. Proc. Soil Sci. Soc. Am., Vol. 7. 1942.
2. Bushnell, T. M. Taxonomic considerations in soil correlation. Report of Soil Survey Assoc. pp. 110–114. 1934.
3. Ellis, J. H. A field classification of soils for use in the soil survey. Sci. Agr. 12 : 6. 1932.
4. Jenny, H. Factors of soil formation, McGraw-Hill Co., N.Y., pp. 70-75. 1941.
5. Kellogg, C. E. Recent trends in soil classification. Proc. Soil Sci. Soc. Am. 3 : 253-259. 1938.
6. Merrill, G. P. Rocks, rock and weathering and soils. Macmillan Co., New York, p. 44. 1897.
7. Thwaites, F. T. Outline of Glacial Geology. University of Wisc. 1941.
8. Weaver, J. E., and F. E. Clements. Plant Ecology, McGraw-Hill Company, N.Y. 1938.
9. Wyatt, F. A., W. E. Bower and W. Odynsky. Soil survey of Lethbridge and Pincher Creek Sheets. Bull. 52. University of Alberta. 1939.
10. Hills, G. A., N. R. Richards and F. F. Morwick. Soil survey of Carleton County. Report No. 7, Ontario Soil Survey. 1944.
11. Hills, G. A. and F. F. Morwick. Soil Survey of Northwestern Ontario. In Press.

PHYSICAL FACTORS AFFECTING LAND USE IN A COMMON SOIL TYPE IN ONTARIO[1]

N. R. RICHARDS[2]

Experimental Farms Service, Ottawa, Ontario

Farm lands in the Province of Ontario have a wide range of physical conditions that affect their use. These may be expressed on a detailed map by delineating areas showing soil type, degree of slope, and kind and degree of erosion. Present land use must be recognized since it may have a very decided effect on the extent to which a soil type suffers from the hazards of erosion.

A "Soil Type" (2) may be defined as a group of soils having genetic horizons similar as to differentiating characteristics, including texture and arrangement in the soil profile, and developed from a particular type of parent material. However any soil type is actually an expression of a range of conditions. A type characterized by level topography will not exhibit as many variations as one characterized by rolling topography. On the latter there is a wide range in degree of slope, drainage conditions, and the extent to which the type suffers from erosion hazards. A level soil type may be represented entirely in one slope class while one with rolling topography may be contained in several classes as is the case in the type under discussion. The smoother slopes, with good farming practices, can be cultivated without fear of excessive erosion. However, on the steeper slopes care must be exercised to protect the surface soil from eroding away since a definite relationship exists between degree of slope and soil losses. On a level soil type the drainage is usually relatively uniform throughout whereas on a rolling type it may vary from good drainage on the smooth slopes to excessive drainage on the steep slopes.

More than 75,000 acres of Bondhead fine sandy loam were recognized and mapped in Durham County and slightly more than 50,000 acres in Northumberland and York Counties. Formed from materials which are comprised largely of Trenton and Black River limestone the Bondhead fine sandy loam is commonly referred to as a till soil. The rolling topography provides adequate drainage over most of the type with the exception of the steep slopes which are often excessively drained. Stones are present throughout the soil profile, but not in sufficiently large numbers to interfere with cultivation. This soil exhibits a well developed profile common to the Grey Brown Podsolic soils and is described in Figure 1.

Mixed farming is the dominant type of agriculture being practised on the type. Small grains and hay are grown to feed live stock. Production of butterfat, beef cattle, swine and poultry form the basis from which the farm income is derived. Oats, wheat and barley are the most common grain crops grown.

Slightly over 4,000 acres of Bondhead fine sandy loam were examined in detail in a sample area of Hope Township, Durham County and an inventory made of the physical factors that affect the use of this soil type.

[1] Presented to the Soils Group of the Canadian Society of Technical Agriculturists at the Annual Convention, Toronto, Ontario, June 26–29, 1944.
2. Agricultural Scientist, Experimental Farms Service, c/o Ontario Agricultural College, Guelph.

A_1 horizon 6 inches grey brown fine sandy loam; friable crumb structure; neutral to slightly alkaline reaction; stones common in the surface soil.

A_2 horizon 8–12 inches pale yellow brown fine sandy loam; stones common.

B horizon 3–6 inches dark yellow brown loam to clay loam.

C horizon grey, loamy, calcareous till dominated by limestone materials.

FIGURE 1. A cultivated profile of Bondhead fine sandy loam.

Present land use or cover was charted on aerial photographs. A series of vertical photographs taken in 1927 was obtained from the R.C.A.F. and formed a very useful and satisfactory base upon which to chart present cover. All lands planted to crops, fallow land, orchards and areas seeded down to crops grown in rotation were considered "*Cropland*". At the time of the survey 72% of the Bondhead fine sandy loam was contained in the Cropland class. Areas used for grazing and not in the regular system of crop rotation were mapped as "*Permanent Pasture*" and occupied 23% of the surveyed area. Much of the permanent pasture is located on the steep slopes as indicated in Figure 2 while the smooth slopes are cultivated. Land with 40% or more of its surface covered by trees was considered "*Woodland*". A little less than 4% of the Bondhead fine sandy loam in the surveyed area is under tree cover. The remaining 1% of the area was considered "*Idle Land*".

Present Land Use	*Percentage of area*
Cropland	72
Pasture Land	23
Woodland	4
Idle Land	1
Total	100

Slope affects the rate of run-off and consequently the susceptibility of a soil type to erosion. Slope was measured by use of the Abney Level, and six classes were established to express this factor.

TABLE 1.—SLOPE CLASS AND PERCENTAGE OF AREA OCCUPIED

Slope class	Area occupied
	%
A — 0–3%	1.8
B — 3–8%	43.5
C — 8–15%	43.2
D — 15–25%	6.8
E — 25–35%	2.8
F — 35% and over	1.9
Total	100.0

An experiment conducted at the La Crosse Experiment Station, La Crosse, Wisconsin (1) compares the soil losses from slopes of 3, 8, 13 and 18%. There are 3 plots on each slope, and the individual plots are 72 feet long up and down. Measurement of soil losses was made for two years with all twelve plots planted to barley. The average annual soil lost per year has been:

Percentage slope	*Average annual soil loss*
%	tons
3	0.69
8	2.34
13	6.80
18	17.19

It is interesting to note that the 18% slope is less than twice as steep as the 13% but the soil loss is almost three times as great. As the slope becomes increasingly steep the soil losses continue to increase even more rapidly. The erosion hazards are multiplied as the steeper slopes are cultivated.

Crops vary greatly in the amount of protection from erosion that they give to the fields on which they are growing. Permanent cover crops such as hay, pasture and woodland tend to hold the soil in place and reduce erosion because: (1) they cover the soil completely the year around, and (2) add to the organic matter and granulation of the soil thus increasing the water absorbing capacity which in turn decreases surface run-off. Cultivated crops, particularly row crops, usually increase soil erosion because they: (1) reduce soil granulation and the organic matter content of the soil thereby lowering the water-holding capacity and increasing the surface run-off; (2) do not occupy the soil throughout the year; and (3) do not cover the soil completely. Table 2 expresses the distribution of present land use according to slope group.

TABLE 2.—DISTRIBUTION OF PRESENT LAND USE ACCORDING TO SLOPE GROUP

Present land use	A slopes 0–3%	B slopes 3–8%	C slopes 8–15%	D Slopes 15–25%	E Slopes 25–35%	F Slopes 35% and over
	%	%	%	%	%	%
Cropland (2,892 acres)	2.1	48.0	43.9	3.8	1.9	.3
Pasture Land (932 acres)	1.7	35.6	40.8	11.6	3.4	6.9
Woodland (132 acres)	0	2.9	41.2	32.4	17.7	5.8
Idle Land (54 acres)	0	30.8	61.6	7.6	0	0

The figures in Table 2 indicate that almost half the area in cropland is located on slopes greater than 8%. Because of steep topography and susceptibility to erosion there has been a tendency to retire the areas having steep slopes to permanent cover of woodland or pasture.

The Bondhead fine sandy loam is susceptible to sheet erosion, and to express this factor five erosion classes were established.

Erosion Class	*Percentage of Area*
Little or no erosion	7.6
Slight erosion	43.6
Moderate erosion	38.8
Severe erosion	3.7
Very severe erosion	6.3
Total	100.0

TABLE 3.—DISTRIBUTION OF PRESENT LAND USE ACCORDING TO EROSION CLASSES

Present land use	Little or no erosion	Slight erosion	Moderate erosion	Severe erosion	Very severe erosion
	%	%	%	%	%
Cropland	5.9	43.4	44.1	2.7	4.1
Pasture land	13.3	45.5	26.2	5.2	9.8
Woodland	15.2	33.3	27.3	12.1	12.1
Idle Land	0	54.1	55.9	0	0

Because of its rolling topography and the extent to which it is cultivated the Bondhead fine sandy loam presents an acute erosion control problem. Special attention must be paid to the selection of suitable rotations, adapted farm crops, and to the application of erosion control practices if this soil type is to be successfully farmed. Pastures for the most part are located on land which was formerly used for crops. Erosion on pastures, therefore, is more severe than it would have been if the land had been maintained in grass. Some of the area mapped as woodland are plantings on severely eroded areas. Other wooded areas have been pastured and are showing signs of accelerated erosion. A large percentage of the idle land on the

Bondhead fine sandy loam will be cultivated again when sufficient labour and equipment are available. However over 55% of the area that is idle now will require intensive erosion control practices when cultivated.

FIGURE 2. Smooth slopes on the Bondhead fine sandy loam are cultivated, while the steeper slopes are used for pasture.

After the four factors, soil type, present cover, degree of slope, and erosion have been measured they form the basis for planning improved land use on the surveyed area. Although each of the factors is significant in itself, it is desirable to group them into a simple classification that will express the capabilities of the land for use. Five categories were established on the basis of the physical characteristics which determine the capability of the land for use. Classes I, II, and III include land that is suitable for the regular use of growing crops that require tillage. Classes IV and V are not suitable for continuous cultivation and are best adapted for pasture or forest land.

Class I land can be cultivated safely and permanently without the use of special erosion control practices. Except for practices necessary to replace plant nutrients removed by crops, and the maintenance of good soil tilth, land in this class is capable of producing moderate to high yields of general farm crops. About 7.6% of the Bondhead fine sandy loam is contained in Class I.

Class II land can be cultivated safely provided fertility levels are maintained and protective measures such as the incorporation of legumes in the grass seed mixture and the maintenance of waterways in sod are employed to protect the soil from erosion. About 42% of the surveyed area is Class II land.

Class III land occupies 39% of the area. Land in this class is suitable for cultivation provided complex or intensive erosion control practices are employed. In this class, it may be necessary to use contour cultivation or strip cropping. Every effort must be made to conserve as much soil moisture as possible.

Because of steep slopes, irregular topography, or severe erosion, over 4% of the Bondhead fine sandy loam included in Class IV land would serve its greatest usefulness as Pasture Land.

Land Class V contains very severely eroded areas with rough, steep and broken topography. Even under grass cover, land in this class erodes readily. Forest cover is recommended for about 9% of the Bondhead fine sandy loam.

Land Class	*Percentage of Area*
I	7.6
II	41.8
III	37.2
IV	4.3
V	9.1
Total	100.0

Such an inventory of any soil type forms the basis for the development of improved land use. The results indicate that erosion control measures are urgently required if the land is to serve its greatest use capability. However, before recommendations are made, specific knowledge, field by field, must be obtained and the suggested protective measures must be fitted into an acceptable farm plan.

ACKNOWLEDGMENT

Much of the data presented in this article is taken from the report of the Soil Erosion and Land Use Survey of the Hope Township Project Area. Sincere thanks are due Professor F. F. Morwick who supervised the field work and the writing of the Hope Township Report.

REFERENCES

1. Cropping Systems that help control erosion. U.S.D.A. Bulletin 452.
2. Soils and Men. Yearbook or Agriculture, 1938. U.S.D.A.

CEREAL VARIETY ZONE
CO-ORDINATION IN THE PRAIRIE PROVINCES

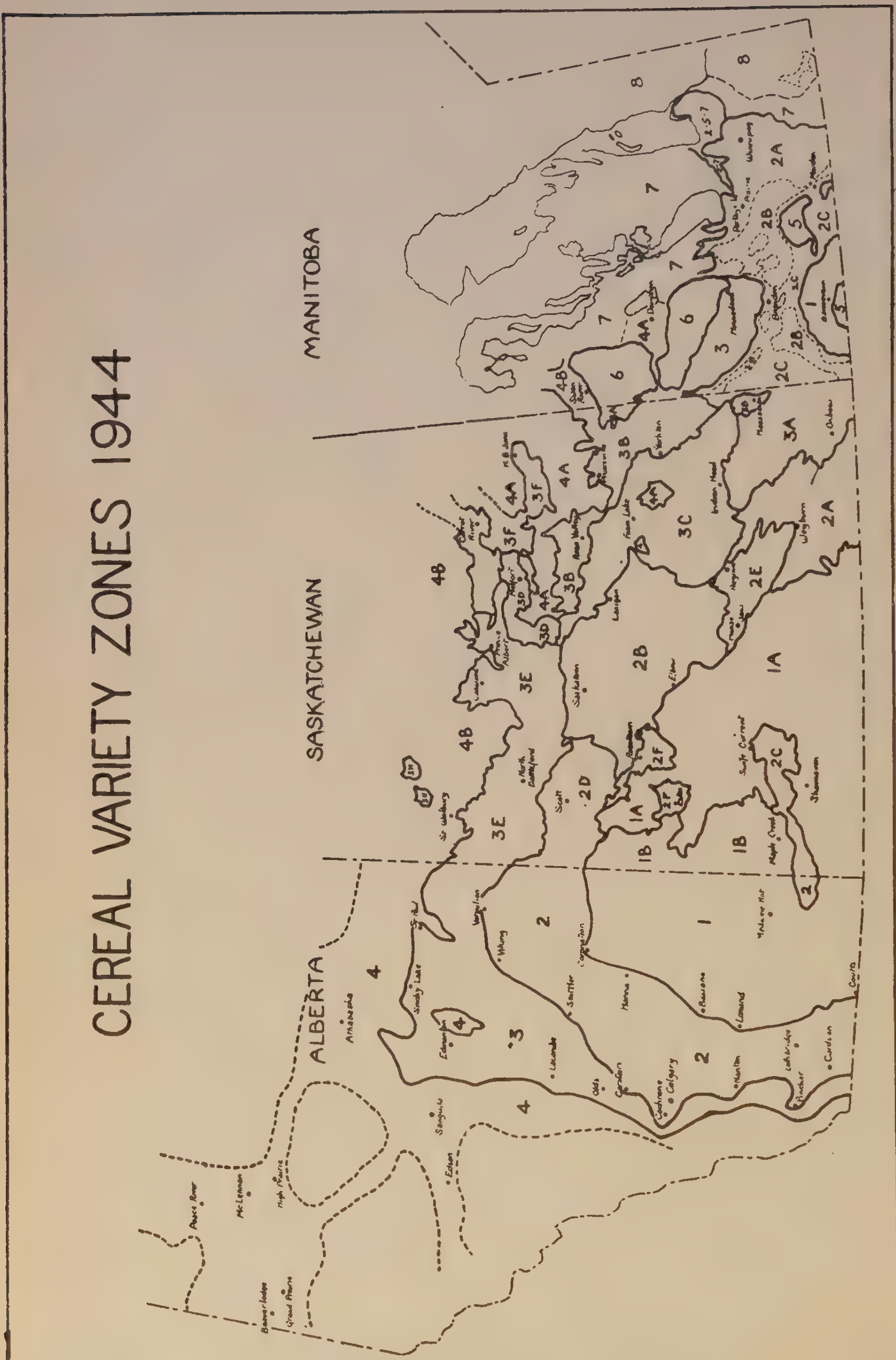
[Received for publication February 15, 1945]

For the past 15 years the Cereal Variety Zone Co-ordination Committee of the Western Canadian Society of Agronomy has functioned to give coherence to the recommendations of the cereal committees of the three prairie provinces. The main purpose of the committee is to co-ordinate at the provincial boundaries the cereal zone boundaries and variety recommendations. The committee consists of six members, two being from each province as follows: Alberta, Dr. A. G. McCalla, University of Alberta, Edmonton, and Mr. W. D. Hay, Dominion Experimental Station, Lethbridge; Manitoba, Dr. C. H. Goulden, Dominion Laboratory of Cereal Breeding, Winnipeg, and Mr. W. J. Breakey, Dominion Experimental Farm, Morden; Saskatchewan, Mr. J. G. Davidson, Dominion Experimental Farm, Indian Head, and Dr. J. B. Harrington, University of Saskatchewan, Saskatoon (Chairman). Two of the previous reports of this committee have been published in *Scientific Agriculture*, namely, in 1933 in vol. 13, pp. 473-475, and in 1936 in vol. 17, pp. 259-263.

The co-ordinating committee, at its last annual meeting, which was in June, 1944, at Saskatoon, adopted the plan of preparing for publication a brief annual report accompanied by an up-to-date cereal zone map of the prairie provinces. It was considered that there was, among the technical agriculturists of Canada, sufficient general interest in cereal zonation to warrant the publication in January or February each year of a co-ordinated picture of the current cereal variety recommendations for the prairie provinces.

In order to have more effective co-ordination of the zones and recommendations which are drawn up and approved by the cerealists of the prairie provinces, the three cereal committees, at the suggestion of the co-ordination committee, have staggered the dates of their meetings and arranged for a representative to attend the meeting of the cerealists of the adjacent province where possible. For example, the Alberta Varietal Zonation Committee, and the Manitoba Agronomists, which includes the Manitoba Cerealists, held their 1944 annual meetings the middle of December, one week before the Saskatchewan Cereal Variety Committee had its meeting. The interchange of representatives at the meetings of the cerealists, although not yet consummated as completely as is desirable, has already been most valuable in the promotion of co-ordination.

Staggering the dates of the meetings and exchanging delegates would not of itself effect co-ordination. The Alberta and Manitoba committees are well aware of the desirability of making no zone boundary change or recommendation that would upset the status quo without first taking up the point with the Saskatchewan Cereal Variety Committee and trying to come to a decision that would be satisfactory to the provinces concerned. Similarly the Saskatchewan cerealists, because their province is adjacent to each of the other provinces, realize the need for synchronizing Saskatchewan zone boundary changes and recommendations with those of Manitoba and Alberta.


CEREAL VARIETY ZONES 1944
MANITOBA
SASKATCHEWAN
ALBERTA

ZONES

The cereal variety zones of the prairie provinces follow the soil zones very closely and in Alberta and Manitoba are almost synonomous with the soil zones. These zones are designated by arabic numerals with, in most cases, sub-divisions indicated by letters. The sub-divisions are to accommodate cereal variety recommendations where climatic differences, important to cereal variety growth and ripening, occur. The principal characteristics of the basic soil zones furnish a rough background for varietal recommendations. In Alberta and Saskatchewan the shallow brown soils subject to frequent drought constitute Soil Zone 1. Zone 2 comprises the dark brown soils and in Alberta the shallow black soils, and is less subject to drought. Zone 3 includes the black, deep black and degraded black soils and has much better moisture conditions than Zone 2. Grey and strongly degraded black soils and a relatively short frost-free season characterize Zone 4. In Manitoba Zone 1 is transitional like Zone 2 of the other provinces, Zones 2, 3 and 4 are different types of black soil, Zones 5 and 6 are somewhat comparable to Saskatchewan Zone 4, and Zone 7 comprises wooded areas with soil of high lime content.

VARIETY RECOMMENDATIONS

Factors Considered

There are a number of basic considerations which determine the recommendations of varieties. Some of the more significant factors are the following:

Yield is the most important and itself depends on various inherited and environmental factors. A variety may yield better in Manitoba or Alberta than in Saskatchewan, or vice versa, and it is recommended accordingly. Regardless of its potential yield a variety may not be recommended for a given area if its susceptibility to disease, or weather conditions, etc., makes its use there hazardous.

Length of growing season of a variety is very important where it is likely to exceed the normal frost-free period. For example, only early varieties of wheat and flax would be recommended in the northern parts of Alberta and Saskatchewan. On the other hand, oats with a short growing period do better than late oats in the southern areas of Saskatchewan and Manitoba.

Strength of straw is of chief significance in the moister areas where yields are high, but it is of general importance throughout the West; even in the dry areas occasional crops grow tall and rank.

Reactions to specific diseases are important according to the likelihood of epidemics. For example, stem rust of wheat may cause serious loss in Manitoba and Saskatchewan but the danger is slight in western Saskatchewan and Alberta. To a certain extent the same is true of rust in barley, oats and flax.

Length of straw, bushel weight and *resistance to shattering* and *after harvest sprouting* all may be deciding factors under certain conditions.

Wheat

Thatcher is recommended throughout the prairie provinces which shows that this variety suits widely varying conditions. Regent is not recommended in Alberta nor is it recommended in any adjacent zone of Saskatchewan excepting 3E and in that case it is only considered well suited to the eastern part of the zone. Regent is recommended in all adjoining zones of Manitoba and Saskatchewan. Renown is recommended in Manitoba Zones 3, 4B and 6 but not in Saskatchewan. This is not inconsistent as Renown has yielded comparatively better in Manitoba than in Saskatchewan.

Reliance is recommended for Zone 1B of Saskatchewan and Canus for Zones 1 and 2 of Alberta. These are high yielding sister varieties of similar performance and both are susceptible to rust, which is much more important in Saskatchewan than in Alberta and accounts for the restricted recommendation of Reliance, compared with that of Canus. Somewhat similarly, Marquis and Red Bobs, both susceptible to rust, are recommended in Alberta but not in Saskatchewan excepting for the small northwestern zone 3H. Rust-susceptible varieties are discarded earliest where the rust threat is greatest. Thus no rust-susceptible variety of wheat is recommended in Manitoba, only two are recommended in Saskatchewan and they are restricted to the extreme west, and in Alberta no variety has been discarded because of susceptibility to rust.

As for *durum* wheat, Mindum is recommended for Zones 1 and 2 in Manitoba and for eastern Saskatchewan; Pelissier, which is more drought resistant than Mindum, is recommended for central and western Saskatchewan while in Alberta no durum is recommended. These recommendations are to be expected since the principal reason for using durum varieties in Western Canada has been their resistance to rust.

Oats

Oat recommendations also make a coherent picture, stress being laid on rust resistance in Manitoba, drought resistance plus rust resistance in Saskatchewan, and yield and straw strength in Alberta. In Manitoba, Ajax and Vanguard are recommended in all zones and Exeter in Zones 3 and 7. In Saskatchewan, Vanguard is no longer recommended, it being replaced by Ajax and Exeter which outyield Vanguard under the drier conditions of that province. Banner and Victory, although susceptible to rust, are still recommended in many zones but none of these adjoins the agricultural areas of Manitoba. These varieties are much alike and the recommendation of Banner in Zones 1A, 1B and 2D of Saskatchewan and Victory in the adjacent zones of Alberta, Zones 1 and 2, is probably largely a matter of local preference and does not signify an important divergence in viewpoint. Neither Ajax nor Exeter are recommended in Alberta because rust has not been a factor in oat production and because the older varieties Legacy and Eagle have done well in Alberta as early and late varieties, respectively.

Barley

In discussing barley recommendations two things should be kept in mind. These are (1) the need for drought resistant varieties on the open plains of Saskatchewan and Alberta, and (2) that Newal does best toward the West and North whereas Wisconsin 38 and Plush do best in the East. In Manitoba, Plush, Wisconsin 38, Sanalta and Rex are recommended as feed barleys in all zones. For the adjacent zones of Saskatchewan, Plush and Rex are recommended but not Wisconsin 38 or Sanalta. In Alberta, Newal, Trebi and Sanalta are recommended for Zones 1 and 2; these varieties plus Olli are named for the irrigated areas. In Zone 2, Newal and Olli (North only) are recommended and the same varieties are recommended in Zones 3 and 4. In Saskatchewan, Prospect and Rex are recommended for Zone 1, and Newal, Plush and Regal along with Rex in the Zones 2D, 3E and 4B which are adjacent to Alberta. In Alberta the performance of Newal has been so satisfactory that it is the only smooth-awned variety recommended. It would seem that greater co-ordination of feed barley recommendations at the Alberta-Saskatchewan boundary should be sought. However, the present apparent lack of co-ordination is not serious considering that conditions in eastern Alberta are not identical with those of western Saskatchewan.

For malting barley O.A.C. 21 is recommended in all zones of Alberta, the northeastern and eastern zones of Saskatchewan, and all of the Manitoba zones excepting the southwestern region. In addition Olli is recommended for Zones 3 and 4 of Alberta, and Mensury is an alternative to O.A.C. 21 in Manitoba. The principal lack of co-ordination here is the recommendation of O.A.C. 21 for the open plains zones of Alberta but not of Saskatchewan. However, it is recognized by the cereal committees of these provinces that the growing of malting barley should not, as a rule, be attempted on the dry open plains. Mensury is very similar to O.A.C. 21 and was omitted from recognition by the Saskatchewan cerealists on that account. Thus there is excellent agreement between Manitoba and Saskatchewan as to malting barley recommendations. The recommendation of Olli in Alberta is in accord with its favourable mention for northeastern Saskatchewan.

Flax

The flax recommendations show satisfactory co-ordination in that Royal is recommended for all central and southern areas, and Redwing for the northern and other shorter season areas. In Manitoba, Buda does well in some areas and is an alternative to Royal whereas, in Alberta, Bison is recommended along with Royal in Zones 1 and 2. The rust and frost susceptibility of Bison have not been as important factors in Alberta as in Saskatchewan.

CONCLUSION

On the whole there is reasonably satisfactory co-ordination of cereal zones and variety recommendations in the prairie provinces. Undoubtedly the use of a uniform soil classification throughout the Prairie Provinces

would be helpful in bringing about a full co-ordination of cereal variety zones. It is hoped that this materializes within the next few years. A certain amount of discrepancy may continue in the variety recommendations, but this may be more apparent than real. Each committee of cerealists endeavours to keep the number of recommended varieties at a minimum. Thus when one province recommends a given variety A it is less likely to advocate another variety B which is somewhat similar to A but does not excel it. If, then, the adjacent province happened to recomment B first it would similarly not recommend A. Here would be a case where the actual difference in recommendation is slight yet appears to be large. The existing variety recommendations of the Prairie Provinces show more fundamental consistency than is apparent and in general it can be concluded that a fair degree of co-ordination has been achieved.

J. B. Harrington, *Chairman*

February 15, 1945.